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A COMPUTER AIDED PROCESS PLANNING SYSTEM FOR ROTATIONAL PARTS IN FMS ENVIRONMENT

by

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DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

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A COMPUTER AIDED PROCESS PLANNING SYSTEM FOR ROTATIONAL PARTS IN FMS ENVIRONMENT

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MARCH, 1987

Dedicated

To

My Parents

6/3/87

CERTIFICATE

This is to certify that the present work on "A Computer Aided Process Planning System for Rotational Parts in FMS Environment", by V.N. Vittal has been carried out under our supervision and has not been submitted else where for the award of a degree.

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NOMENCLATURE

C_o	Operating cost/min (Rs/min)
C_t	Tool cost per edge (Rs/edge)
D	Diameter of work (mm)
D_{ctr}	Cutter diameter (mm)
D_{dr}	Drill diameter (mm)
F_c	Cutting force developed (kg)
F_{cu}	Upper limit on cutting force (kg)
L	Length of work (mm)
N	Cutting speed (rpm)
N_{tg}	Number of teeth on gear
N_{ctr}	Number of teeth on cutter
P	Power developed (kw)
P_{in}	Power input to machine tool (kw)
R	Radius of job (mm)
T	Tool life (min)
T_{alow}	Allowable torque (kg.mm)
T_c	Tool changing time (min)
T_d	Torque developed (kg.mm)
T_1	Minimum tool life (min)
T_p	Handling time per piece (min)
V	Cutting speed (m/min)
V_1	Lower limit on cutting speed (m/min)
V_u	Upper limit on cutting speed (m/min)
W	Width of cut (mm)
Z	Total machining cost (Rs)

a	addendum (mm)
d	depth of cut (mm)
ded	dedendum (mm)
e	Overtravel of the tool (mm)
f	feed (mm/revolution)
f_l	lower limit of feed (mm/revolution)
f_u	upper limit of feed (mm/revolution)
k	chip reduction coefficient
n	number of passes
t_m	machining time (min)
$\alpha, \alpha_1, \alpha_2,$	
$\alpha_3, \delta, \varepsilon$	constants
ϕ	shear angle
γ	rake angle
η	friction angle
η_m	Efficiency of machine tool

ABSTRACT

In the present work, a computer aided process planning syst for rotational parts in FMS environment (designated as CAPP-RP) ha been designed, developed and implemented. This also presents the design of a database to store engineering data required for the synthesis of process plan. With concepts of FMS and CIMS gaining more and more importance, the flexibilities these systems offer imposes many requirements on process planning. Hence the need for development of a comprehensive computer aided process planning system arises. The process plan thus generated should comprise the operations sequence, optimal machine tool selected for each operation, Machinability Data systems, processing time and as well as cost for each operation.

The CAPP-RP system is capable of handling machining operati like turning, drilling, milling, facing, boring, gear milling etc. efficiently while other operations can also be handled. The syste designed to take care of the requirements of FMS on process planni and is capable of generating alternative process plans whenever on of the machine tools becomes unavailable.

The CAPP-RP system is implemented on DEC-1090 computer syst and programs are written in PASCAL. The system efficiently genera the process plan for four rotational parts taken as examples and alternative process plans were generated for two of the examples.

CHAPTER I

INTRODUCTION

In any manufacturing system, the design conceptualization is to be transformed into working instructions to get the finished product. This is done by means of process planning and is basically a transition step from design to production. With the advent of computers, numerical control concepts, robotics and other automation techniques, the earlier conventional manufacturing system has changed to more sophisticated, highly productive and efficient systems of today. And this has led to the concepts to Flexible Manufacturing Systems (FMS) and Computer Integrated Manufacturing Systems (CIMS). Along with the advantages the automation has brought various challenges to the engineers/researchers and process planning is one such area which has attracted the attention of researchers because it is the link between design and production functions.

1.1 MANUFACTURING SYSTEMS AND FUNCTIONS IN MANUFACTURING SYSTEMS

A manufacturing system is one in which the basic resources like man power, materials, machines and methods are utilised to produce usable tangible and intangible products. Though the advances made in science and technology keep changing the input form (with the development of new machine tools, cutting tools, methods, materials material handling systems etc.) the basic

concepts of transformation process in manufacturing system has remained unchanged.

The various functions performed in any manufacturing system may be broadly classified into Design and Manufacturing. Design function converts the concepts of the designer about the product into a set of product design specifications. This is later converted into a form which can be easily understood by manufacturing or production personnel, to transform the available resources into finished product. The conversion of design specifications into working instructions is done by a process planner and the function is termed as process planning or operations planning. This is one of the most important function in any manufacturing system since it is the link between design and manufacturing.

1.2 AUTOMATION AND COMPUTER AIDED DESIGN/MANUFACTURING:

Automation is defined as the technology concerned with the application of complex mechanical, electronic and computer based system in the operation and control of production (Groover [1]). Over the last few decades, the automation has decreased the human interaction in manufacturing to a great extent with the development of numerical control (NC), Computerized Numerical Control (CNC), industrial robots and computers.

The application of computer system to assist in the creation, modification, analysis and optimization of the design of a product is termed as Computer Aided Design (CAD)(Groover [1]

The CAD system includes hardware (Computer, graphic display, keyboard etc.) and software (programs to implement computer graphics and application programs for engineering design) and is basically a computer intensive function.

Computer Aided Manufacturing (CAM) can be defined as the use of computer systems to plan, manage and control the operations of a manufacturing plant through either direct or indirect computer interface with plant's production facilities. The application of CAM may be either computer aided process monitoring and control and manufacturing support applications. The former may be termed as online application while the later as off-line application of computers in manufacturing (Groover[1]).

1.3 COMPUTER INTEGRATED MANUFACTURING SYSTEMS (CIMS) AND FLEXIBLE MANUFACTURING SYSTEMS (FMS):

The main objective of any manufacturing system is to produce the products of right specification on right time at minimum cost. This calls for the total co-ordination between various departments of the organization and hence their integration. The development of computers and improved information processing techniques offers a good opportunity to integrate hitherto separated areas of production activities as well as design functions.

CIMS means the integration of hardware, software, database and information flow paths to perform various activities in manufacturing right from the stages of conceptualization of a product and its design to final inspection with all intermediate

functions like process planning, production planning and scheduling, inventory management etc. into a single entity and driven by a common database under the control of a master computer.

The main emphasis in CIMS is on integration of computers and database with various manufacturing activities of the organization. A CIMS set-up can be represented as shown in Fig. 1.1 [2].

One of the basic block of any CIMS set-up is FMS. An FMS consists of group of materials processing stations comprising of NC, CNC, DNC, machining centres with auto tool changers and robots all linked together with a automatic material handling system along with automated storage and retrieval systems, all under the control of a master computer.

The components of an FMS like machining centres with auto tool changers which is capable of doing different or multiple operations in the same set-up imparts a certain amount of operational flexibility to the whole system. The three types of flexibilities that FMS offers are as outlined below [3].

(i) Process Flexibility:

Ability of performing an operation in more than one way whenever a machine tool breaks down or a tool is not available then the system must be capable of adopting a new route/plan to finish the job.

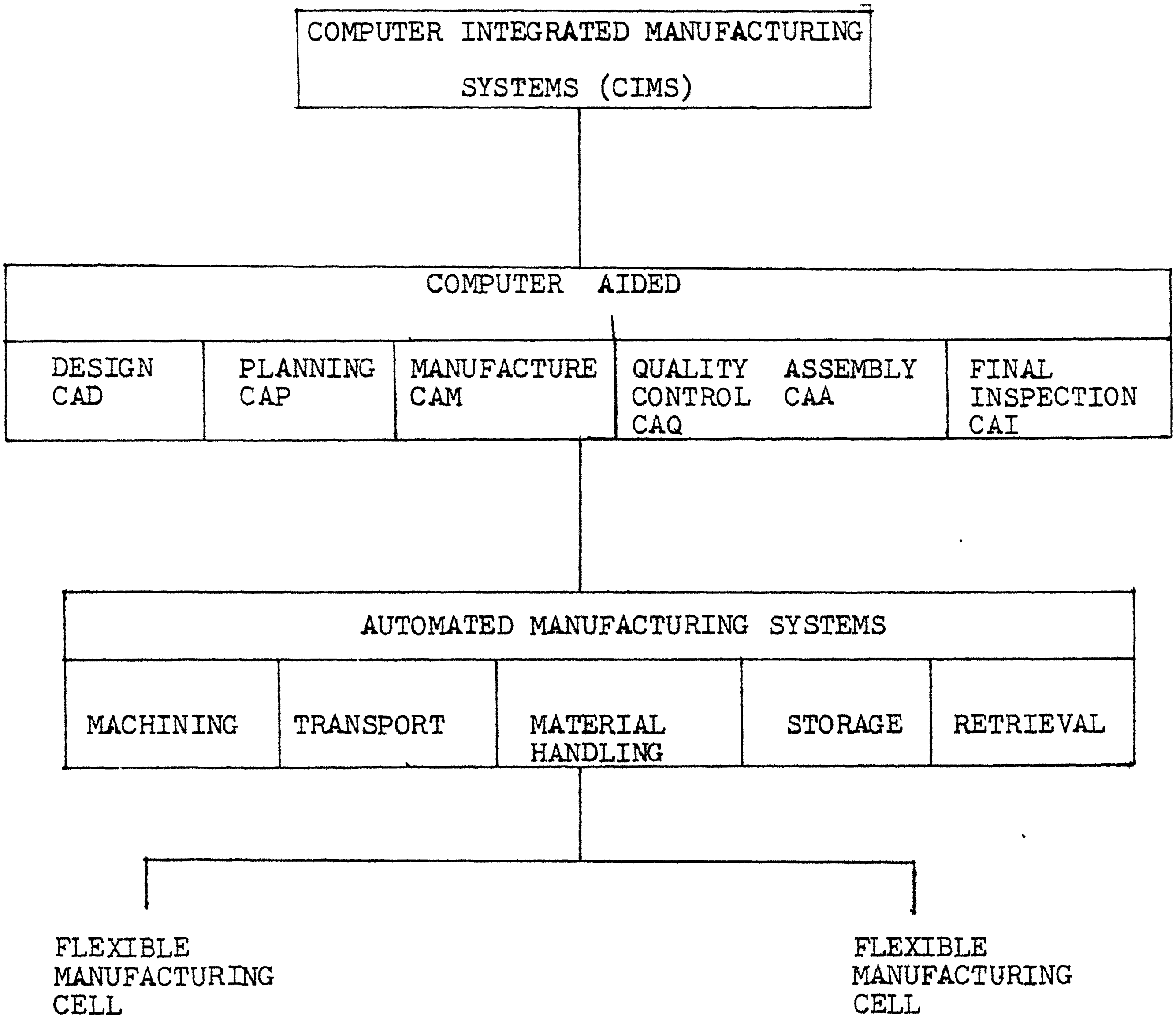


Fig. 1.1: A Schematic Representation of CIMS Set-up.

(ii) Program Flexibility:

Ability of the system to run virtually unattended. This can be attained by better computer control and software techniques.

(iii) Product Flexibility:

Ability to produce new products for a defined cost of new fixtures, tools and part programs etc.

1.4 PROCESS PLANNING AND COMPUTER AIDED PROCESS PLANNING (CAPP):

As already mentioned, process planning is the link between design and production functions of any manufacturing system. Process planning is defined as "the subsystem responsible for the conversion of design data into working instructions"[4]. The development of computers and hence CAM has led to the automation of process planning as well. Hence, CAPP may be defined as a subsystem in manufacturing system where in determination of type of processes, the sequence of machining operations, selection of machine tools and cutting tools along with required jigs and fixtures and determination of cutting parameters are done with computer as an aid. For an integrated CAD/CAM and hence CIMS to be a reality, the link between design and manufacturing i.e. process planning should be strengthened.

1.4.1 Techniques of Process Planning:

The techniques of process planning are best described by [4]. The two important techniques of process planning are

(i) Variant approach

(ii) Generative approach

Variant approach of process planning essentially consists

of the following steps.

1) Building a menu or catalogue of process plan either for a single part or for a family.

2) Creating the software necessary to examine the parts that is being planned and find the closest facsimilie in the menu and to retrieve the associated plan.

On the other hand the generative approach is the logical creation of a process plan from information available in the engineering database with or no intervention by the planner [5]. Hence generative technique synthesizes the process plan with a predefined logic from design specifications making use of existing database in which the required information about machine tools, cutting tools, jigs and fixtures and other machining parameters are stored. Basically generative technique consists of the following steps.

1) Describing a part in detail (viz. both geometric and manufacturing features of the part).

2) Describing a menu of process available to produce the part

3) Describing a menu of machine tools and cutting tools for the process.

4) Creating a software to generate the plan.

Variant approach is observed to be not a efficient approach compared to generative technique because the plans generated by this method even in best case is only a approximated version which still needs editing.

1.5 ROLL OF DATABASE IN CAPP:

Database (DB) is defined as a collection of operational data with least amount of repetition and stored on a centralized computing facility for the use of various users and retrievable at any time.

In any manufacturing system a large amount of data including engineering data will be required by various departments at many times. The engineering database may be designed to the needs of the particular organization. Database thus designed can store, retrieve, edit, update and delete the data by means of a specialized software called Data Base Management Systems (DBMS).

In process planning function, we will be handling large amount of data pertaining to operations, machine tools, cutting tools and cutting parameters. It is desirable to have these required data in a well structured manner to facilitate easy handling and avoid duplication. The database required for any CAD/CAM system is referred to as Engineering database. And depending upon the nature of data stored, engineering database consists of design database, technological database and manufacturing database [6].

(i) Design Database:

At the end of design process, the database must contain a model of the artifacts stating their description. They include geometric models, bill of materials and a part code. Geometric

models represent the geometry of product to be manufactured and are stored in design database from which drawings can be obtained.

(ii) Technological Database:

This consists of data concerning work material (material code, hardness number, stiffness etc.), manufacturing operations, machine tools (designation, list of operations, speed range, power, feed range etc.), cutting tools (designation, material, specifications etc.) and cutting parameters (speed and feed).

(iii) Manufacturing Database:

Purpose is to store all information needed to physically manufacture and assemble a part.

As far as process planning is concerned, it can be said from the nature of data stored, the technological database has more importance than the other two. Design and manufacturing database follow technological database in the same order of importance.

1.6 ORGANIZATION OF THE THESIS:

Chapter II deals exclusively with the literature survey in which the first section makes an overview of the process planning techniques as well as systems. In the second section, need for the current section and its scope is presented.

Chapter III deals with the developed Computer Aided Process Planning-Rotational Parts (CAPP-RP) system with its description, analysis and design presented in separate sections.

Chapter IV deals with implementation details along with description of various modules and the corresponding procedures.

Chapter V deals with test runs, results and analysis.

Chapter VI concludes with discussion on possible improvements for the systems and suggestion for future work.

List of references and appendices is given at the end of the thesis.

CHAPTER II

LITERATURE SURVEY

2.1 OVERVIEW OF LITERATURE:

The importance of process planning as a link between design and manufacturing is being realised and highlighted by many researchers. A lot of effort is being put in the development of new techniques and integration of other fields like database principles, artificial intelligence, decision support systems etc. with process planning. A special sub-committee set-up by CIRP is coordinating the research work of production engineers in this field all over the world.

Process planning whether it is computer aided or manual is divided into following phases [4].

(i) Selection of operations
(ii) Selection of suitable machine tools
(iii) Selection of cutting tools
(iv) Sequencing and grouping of operations
(v) Selection of jigs and fixtures
(vi) Determination of optimal cutting parameters
(vii) Determination of time and cost
(viii) Printing of process plan

In carrying out the above stages to evolve a process plan requires lot of data handling and computation. The need for an integrated engineering database in any manufacturing system is already discussed in Chapter I.

The work done so far in this field can be broadly categorised into two distinct classes. One is mathematical modelling approach and the other is classical approach (i.e. developing an algorithm for a defined problem based on one's knowledge of preparing the route sheet and developing a computer software for the same). Most of the literature available belongs to the second category viz. classical approach.

Kusiak [7] has suggested a mathematical modelling approach in which integer programming technique is used for process planning. He has proposed three models which are to be employed jointly to generate the process-plan for a part. Two models are basically used to generate a feasible set of tool paths (viz. different methods of reducing the blank to finished part) without taking into consideration any of the technological constraints. The problem is solved by cutting plan algorithm and lagrangian relaxation algorithm.

By the above two models, we get only a feasible set of tool paths. The problem of ordering these tool paths and generating the optimal process plan is formulated and solved as a topological ordering problem, taking into consideration all the technological constraints.

The above approach has certain drawbacks. It requires the development of an intelligent procedure to generate only the feasible tool paths, accounting for the technological constraints set. Other stages such as selection of operations, machine tools cutting tools, jigs and fixtures, optimal cutting parameters etc. will have to be performed separately. Thus, this procedure of mathematical modelling approach is more helpful in sequencing and grouping of operations.

Compared to mathematical modelling approach, the classical approach has attracted more attention of the researchers. In this approach, the various stages of preparing a process plan are identified and suitable criterions are established to carry-out these stages. Many process planning systems with computer as an aid have been developed with different criterions employed for various stages.

Determination of cutting parameters (viz. feed, speed and depth of cut) is one important stage of process planning and lot of work has been done in it. It is also termed as Machinability Data Systems and the existing methods employed to determine optimal cutting parameters are as follows [8].

(i) Data Retrieval Method: This is one in which the cutting data for various operations for a variety of work-tool material combination are stored in handbooks or a computer database. These are data compiled over years of experience of shop floor and cannot be taken as authoritative at all times. The another major drawback is that it requires tremendous amount of memory space to store the data.

(ii) Empirical Relations Method: Another method of evaluating speed, feed and depth of cut is by making use of already established empirical relationships which are based on experimental observations. Once again, this method may lead to erroneous results because of the variations in experimental set-up, envir nmental conditions and machining conditions.

(iii) Optimization Mathematical Method: This is the best possible solution for machinability data systems, in which mathematical approach is employed to arrive at optimum machining parameters. Usually adopted optimization criterion are to minimize production cost, minimize production time and maximize profit.

Based on the above criterions, nonlinear optimization problem has been modelled with constraints and solved as unconstrained optimization problem. Hati and Rao [9] proposed a solution methodology for such a modelling, using Davidon-Fletcher Powel's method and thus determine the optimal speed and feed. The problem is modelled both as probabilistic and deterministic models for all the three criterions.

The need for two different approaches arose because some of the parameters involved in the objective function and constraints vary about their mean values and hence this necessitated probabilistic formulation.

This method is employed in the present work also with minimizing production ~~time~~ cost as the objective function with a set of constraints and solved by DFP and as well as Powel's method.

Operations sequencing is another important stage of process planning which needs more attention for the development of intelligent procedures. The presently available method of establishing precedence relationship of operations is by solving a precedence matrix of operations [4]. This involves the maximum interaction of the planner and computer has aided in only computation. Now the present trend is to develop expert systems for sequencing.

2.2 SURVEY OF CAPP SYSTEMS [10]:

Over the last few years, many CAPP systems have been developed. Both variant and generative techniques have been employed in these systems. The available CAPP systems are either for rotational parts or for prismatic parts exclusively. In a recent survey conducted by Eversheim and Schulz [11] for CIRP technical committee, it is reported that atleast 55 CAPP systems are functioning all over the world. A majority of the existing process planning systems are of a variant nature. Most widely referred system is CAM-I automated process planning system (CAPP) developed in 1976. It is a variant system with data base management system written in ANSI standard FORTRAN. The other systems are: MULTICAPP, MIPLAN - which uses the MICLASS coding system for part description. They are data retrieval systems which retrieve process plans based on part code, part number family matrix and code range. By inputting a part code, parts with a similar code are retrieved along with process plans. They are then edited by the user.

Other variant systems are MITURN, MIAPP, ACUDATA, CINTURN, COMCAPP etc.

However, these are some generative systems also, such as CPPP, AUTAP, AM and APPAS. Of these AUTAP is considered to be one of the most complete planning system in use today. This is capable of material selection, process selection, sequencing of operations, machine tool selection, tool selection, lathe chuck selection and part program generation.

These above systems are of different levels of automation and performance. Ideally, a generative system is a turn key system with all the decision logic contained in the software. The system should possess all the necessary information for process planning, therefore, no preparatory stage required. However, this is not the case and most systems require user's decision making at many junctures. It is also observed that so far not even a single general purpose CAPP system which can take care of both rotational and non-rotational parts for a wide range of operations, has been reported.

2.3 JUSTIFICATION FOR THE SELECTION AND SCOPE OF PRESENT WORK:

The three different types of flexibilities that an FMS offers over a traditional manufacturing system are outlined in Chapter I. Scheduling flexibility, which is basically a form of process flexibility, is very important as far as process planning is concerned. It measures the number of different routes by which a given job can be machined. Process planning has direct

impact on scheduling flexibility because for a given part a route corresponds to a variant of a process plan. In conventional manufacturing system usually an assumption is made that for a part only1process plan is available. But in FMS set-up a part may have several alternative plans because of the operational flexibility of the system.

The scheduling flexibility in FMS imposes the following requirements on process planning systems [7].

(i) It should ensure a dynamic generation of process plans with alternative machining routes. This means that the system should be able to generate approximate variants of a process plan in real time.

(ii) In addition, there should be a method to generate plans with a number of cutting tools specified in advance. To avoid redundant change of tools in tool magazine, it may be required to specify the number of tools used for machining of parts.

But, the available systems have not viewed the process planning from FMS point of view. Hence, the current system is developed considering the above requirements of FMS on process planning. The current work is restricted to only a class of parts which always requires turning operation (i.e. rotational parts). Machining operations like turning, drilling, milling, facing, gear milling and boring are supported well on the current system while other operations are also taken care of. The demands of FMS environment on process planning is incorporated in the

system. The concepts of database is also incorporated by developing a representative database for engineering data.

With concepts of FMS, CIMS and as well as AI gaining more and more importance both in industry and research, it is hoped that the present work will contribute in the development of a generalised CAPP system.

CHAPTER III

COMPUTER AIDED PROCESS PLANNING - ROTATIONAL PARTS (CAPP-RP) SYSTEM

This chapter presents description, analysis and design of the proposed Computer Aided Process Planning - Rotational Parts (CAPP-RP) system. System description is presented in Section 3.1, system analysis is described in Sec. 3.2 and system design in the following section.

3.1 SYSTEM DESCRIPTION:

As already mentioned in Chapter II, the system is developed for rotational parts. Machining operations like turning, drilling, boring, milling, gear milling and facing are well supported while other operations like thread cutting (internal and external), grinding, counter-boring, shaping, planning etc. can also be handled. These operations define the operational capability of the system. In order to meet the machining requirements of above mentioned operations, a set of machine tools comprising a horizontal machining centre, a vertical machining centre, a CNC milling machine, a NC stand alone lathe, a CNC turning centre and a CNC grinding machine is considered. Table 3.1 gives the list of machine tool names and their corresponding machine tool code for identification. Table 3.2 gives the different operations along with their

Table 3.1: Machine Tool names and their code.

Machine Tool Name	Machine Tool Code
Horizontal Machining Centre	1
Vertical Machining Centre	2
CNC Milling machine	3
NC Lathe	4
CNC Turning Centre	5
CNC Grinder	6

Table 3.2: Operation name, code and machine tool code.

Operation Name	Operation Code	Machine Tool Code		
Boring deep hole	100	1	2	3
Boring	101	1	2	3
Boring Counter	103	1	2	3
Drilling	120	2	3	4
Drilling deep hole	121	2	3	4
Grinding cylindrical	130	0	0	6
Gear Cutting Bevel	140	0	3	4
Gear Cutting Helical	141	0	3	4
Gear Cutting Spur	142	0	4	5
End Milling	160	1	2	3
Gear Milling	161	1	2	3
Turning Rough	220	0	4	5
Turning Finish	221	0	4	5
Turning Taper	223	0	4	5
Facing Rough	230	1	2	4
Facing finish	231	1	2	4
⋮	⋮	⋮	⋮	⋮

codes and the corresponding machine tools that can be employed to perform them. These codes are used in all subsequent discussions. Specifications of various machine tool are given in Table 3.3.

Assumptions:

Following assumptions are made to delineate various characters of the system.

(i) Operations and Machine Tools: Each operation can be performed on a minimum of one machine tool and a maximum of three. This is done in order to have operational flexibility in the manufacturing system.

(ii) Jigs and Fixtures: Suitable jigs and fixtures are available for all operations.

(iii) Material Handling System: There is a automated material handling system with robots to help the transfer of work parts from work stations to work stations.

(iv) Time Factors: Also assumed that set-up time and non-machining time (due to unavoidable delays etc.) for any operation is a constant proportion of cutting time. This proportion is taken as 0.25 and 0.10 respectively.

3.2 SYSTEM ANALYSIS:

The two modules of CAPP-RP system are:

(i) Plan generating module

(ii) Database Module

Table 3.3: Machine tool specifications.

Status (MCUP)	M/C Tool Code	Speed Low (rpm)	Speed High (rpm)	Power (Kw)	Feed low (mm/revln.)	Feed High (mm/revln.)	Accuracy (mm)	Economic Quantity (nos.)	Ma
0	0	0	0	0	0	0	0	0	–
1	1	10.0	4000.0	40.0	0.05	1.00	0.005	500	HMT
1	2	5.0	5000.0	50.0	0.15	1.50	0.001	1000	HMT
1	3	33.3	3333.3	30.0	0.15	1.75	0.005	400	HMT
1	4	25.0	2500.0	30.0	0.30	1.25	0.010	500	HMT
1	5	15.0	3500.0	40.0	0.10	1.25	0.008	600	HMT
1	6	25.0	5000.0	25.0	0.20	1.75	0.001	500	HMT

3.2.1 Plan Generating Module:

This module consists of various capsules which do various functions in evolving the process plan. A master flow chart of CAPP-RP system is shown in Fig. 3.1.

(a) Coding and Classification Capsule:

Translates the design and manufacturing attributes of a part into a code. Detailed description of each digit of the code is given in Table 3.4(a) and 3.4(b). This code is used as a key to find the part family code to which the coded part belongs. To identify this family the concepts of similarity is employed. Each digit of the part code and that of all the part family codes stored in database for which process plan is available, is compared. If they match then a index value called similarity index is incremented each time. Here it is assumed that each coded attribute is equally important and has the same weightage i.e. 1 in this case.

In the present work a similarity index value of 6 is being employed to decide the part family for any coded part. The 10 digits part code generated is compared with the family codes stored in the database. If there exists a part family code matching with the part code then the process plan code of the family and hence the plan is retrieved. Otherwise generative technique is employed.

(b) Generative Technique Capsule:

For generative technique, the different operations to be performed on the blank to get the finished part are specified

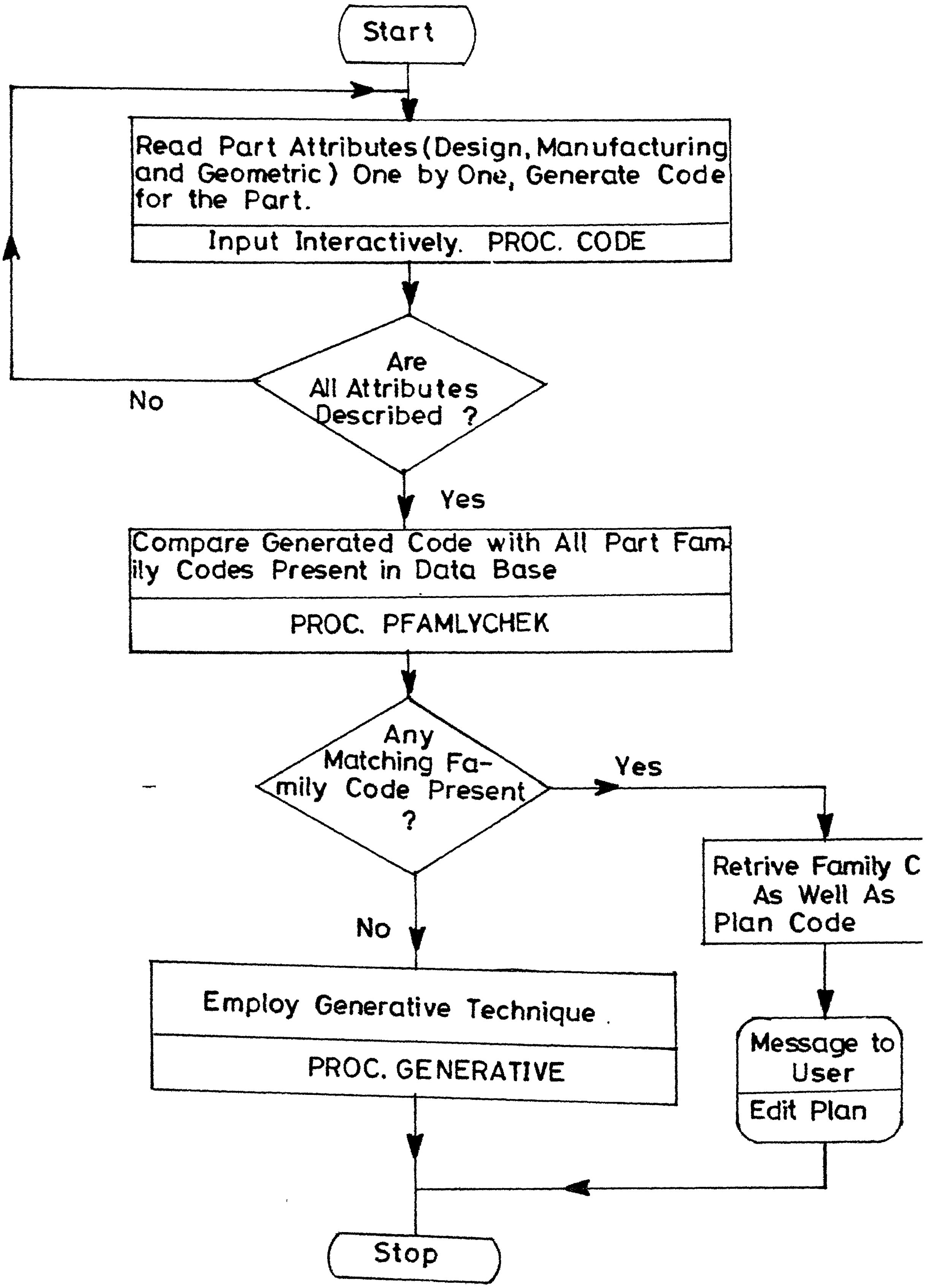


Fig. 3.1 Master Flow Chart for CAPP-RP System.

CODE	L/D RATIO	EXTL. SHAPE & SHAP. ELM.		INTL. SHAPE & SHAP ELMNTS.		OVERALL LENGTH	EXT. AUX. DIMNS.		INT. AUX. DIM OF SHAP. EL.		SURFACE FINISH	TOLERANCE	MATERIAL	ECON. BATCH QTY.
0	>= 5.0	Smooth, No Shape Elmnts.		Smooth, No Shape Elmnts		<= 50.0	No. Dimns. Needed		No. Dimns. Needed		Coarse	<= 0.3	MS	<= 50
1	>5 ≥10	STEPPED AT ONE END/SMOOTH	No Shape Elements	STEPPED AT ONE END/SMOOTH	No Shape Elements	> 50.0 <= 100.0	EXTL. THREADS (PITCH)	<= 1.5	DRILLED HOLES	<= 5.0	Rough	> 0.3 <= 0.6	CI	> 50 <= 300
2	> 10.0	STEPPED AT ONE END/SMOOTH	Threaded	STEPPED AT ONE END/SMOOTH	Threaded	> 100.0	EXTL. THREADS (PITCH)	>1.5 <= 4.5	DRILLED HOLES	>5.0 <= 10.0	Medium	> 0.6	Al. Alloy	> 300 <= 700
3		STEPPED AT ONE END/SMOOTH	Groove	STEPPED AT ONE END/SMOOTH	Groove/ Hole		EXTL. THREADS (PITCH)	> 4.5	DRILLED HOLES	> 10.0	Fine		OTHERS	> 700
4		STEPPED AT BOTH/ MULTIPLE ENDS	No Shape Elements	STEPPED AT BOTH/ MULTIPLE ENDS	No Shape Elements		GEARS (MODULE)	<= 1.5		<= 1.5				
5		STEPPED AT BOTH/ MULTIPLE ENDS	Threaded	STEPPED AT BOTH/ MULTIPLE ENDS	Threaded		GEARS (MODULE)	> = 1.5 <= 30	THREADS (PITCH)	> 1.5 <= 4.5				
6		STEPPED AT BOTH/ MULTIPLE ENDS	Groove	STEPPED AT BOTH/ MULTIPLE ENDS	Groove / Hole		GEARS (MODULE)	> 30	THREADS (PITCH)	> 4.5				
7		Functional Taper		Simple thr/Blind Holes			HALF TAPER ANGLES	<= 8.0	COUNTERBORED HOLE dia	<= 5.0				
8		Operating Thread		Operating Thread			HALF TAPER ANGLES	> 8.0	COUNTERBORED HOLE dia	> 5.0				
9		Others												

Table 3.4 (a)

Coding & Classification System for CAPP-RP.

TYPE OF S.F.	ROUGHNESS VALUES Ra μm
COARSE	12.5 TO 50.0
ROUGH	1.6 TO 6.0
MEDIUM	0.4 & 0.8
FINE	0.001 TO 0.2

Table 3.4 (b)

Surface Roughness Code No.

as input data. For each of the operation specified the following routine is carried out. The flow chart for generative technique is shown in Fig. 3.2.

(i) Selection of Machine Tools: For the operation intended the possible machine tool(s) is(are) retrieved along with specifications and the following criterion are employed for selection of machine tool.

The primary criterion is the accuracy level that a machine tool can provide. If there is more than one machine tool then the secondary criterion viz. optimum machining cost is employed to break the tie. The optimum machining cost is evaluated for optimum speed and feed values. The machine tool having lowest value of machining cost is selected.

The total machining cost is the sum of cutting cost, tool cost, tool changing cost and handling cost. With minimization of total machining cost as objective criterion, the objective function (Z) is written as[9],

Minimize

$$Z = \text{cutting cost} + \text{tool cost} + \text{tool changing cost} + \text{handling cost}$$

which is rewritten as,

$$Z = C_o\, n\, t_m + n\, t_m\, C_t/T + n\, t_m\, C_o\, T_c/T + C_o\, T_p \qquad (3.1)$$

and constraints set is written as,

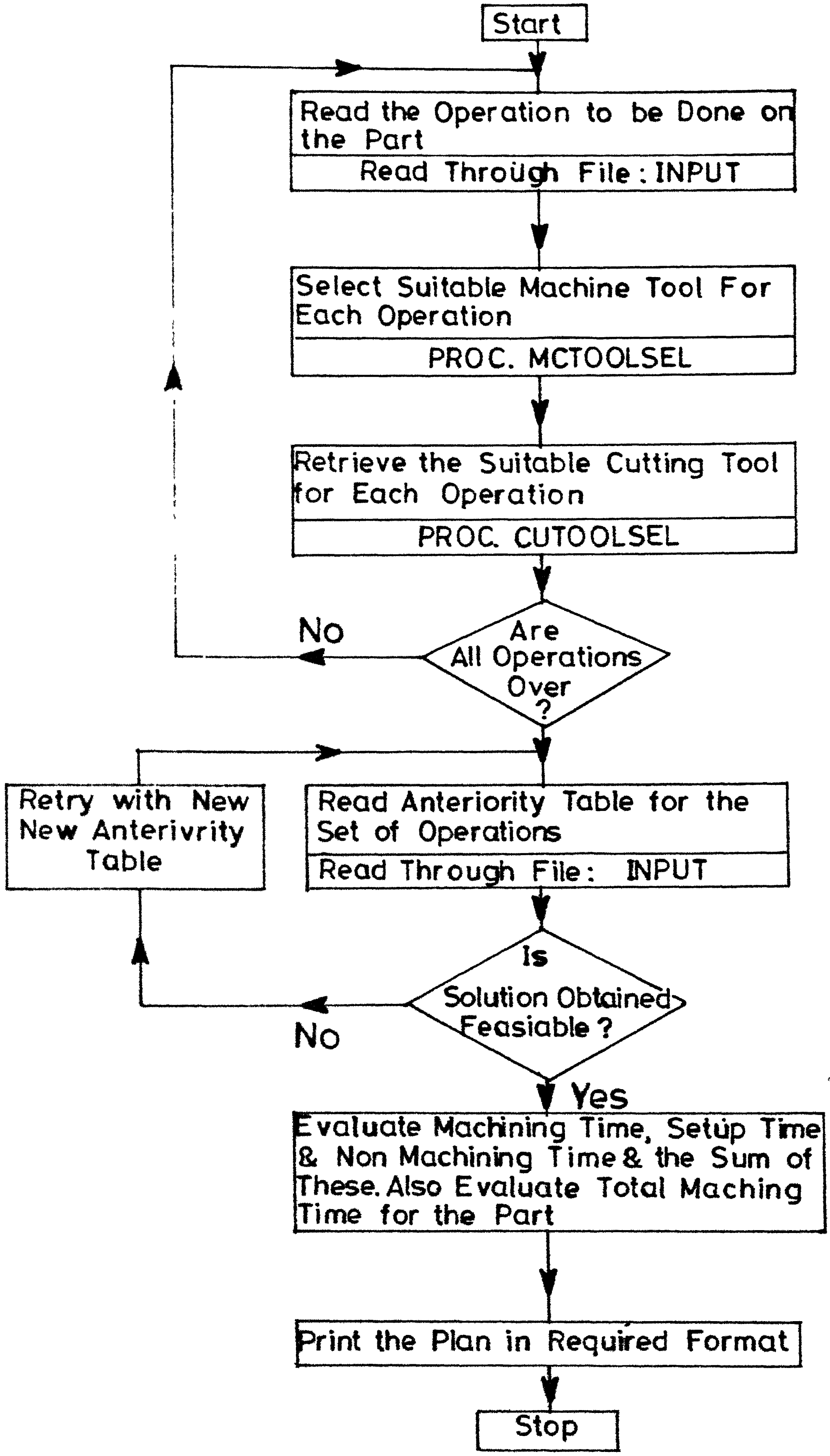


Fig. 3.2 Flow Chart for Procedure Generative.

Bounds on speed: $V_l \leq V \leq V_u$
Bounds on feed: $f_l \leq f \leq f_u$
Bounds on Power: $P \leq P_{in} \quad m$ (3.2)
Bounds on Torque: $T_d \leq T_{alow}$
Bounds on Force: $F_c \leq F_{cu}$
Bounds on Tool Life: $T_l \leq T$

It is observed that the objective function is a function of machining time and tool life which in turn are functions of decision variables speed and feed. Depending upon the operations being done appropriate empirical relations given in Table A-1 are substituted in the equations (3.1) and (3.2).

The solution procedure for solving the above minimization problem is given in Appendix A. A flow chart for machine tool selection is shown in Fig. 3.3.

(2) Selection of Cutting Tools: The cutting tools for an operation can be selected based on the following criterion.

For a given work material, based on the cutting conditions employed the suitable tool material is selected. Thus selected tool material is capable of withstanding the cutting forces, vibrations, shock etc. For example, if low cutting speed is being employed to machine low carbon steel then either alloy steel or high speed steel may be used and at higher cutting speed carbide may be used as tool material.

However, CAPP-RP system tends more towards variant approach, in the sense it retrieves the cutting tool specificatio

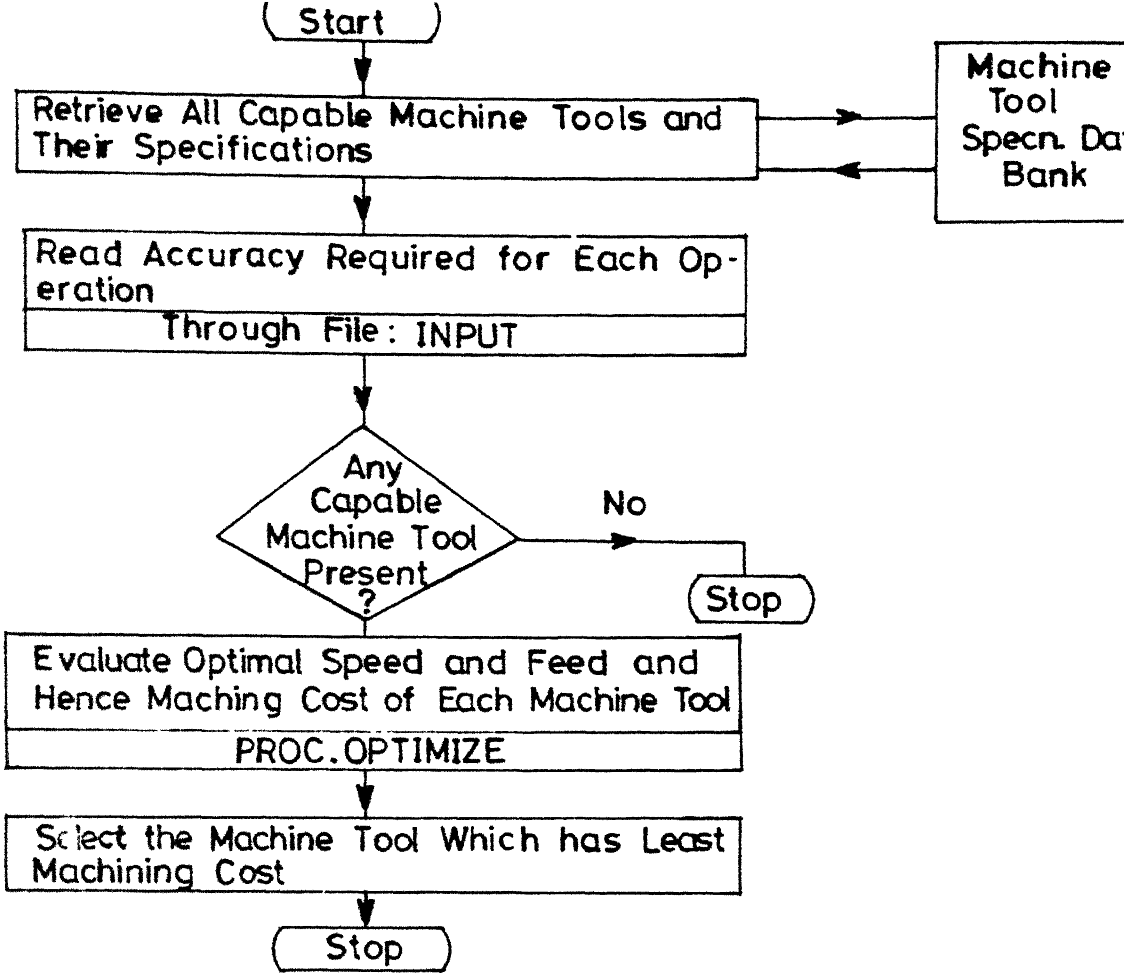


Fig. 3.3 Flow Chart for Proc. Mctoolsel.

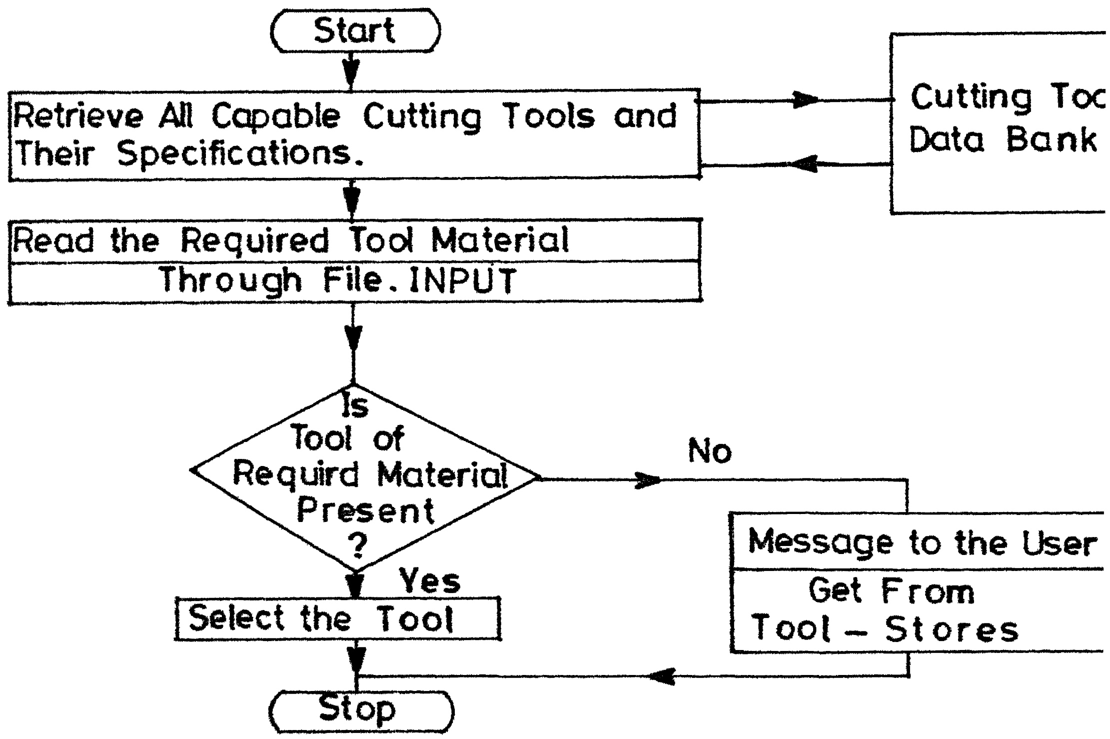


Fig. 3.4 Flow Chart for Proc. Cutoolsel.

for the operations from the cutting tool database. The criteria for retrieval of cutting tool for any operation is the desired tool material decided by the user/planner. And it is assumed that tools thus selected serves the intended purpose.

Jigs and fixtures, as already mentioned in Section 3.1 are assumed to be available for all operations.

(3) Sequencing of Operations: To sequence the intended operations in a logical sequence or order as per technological, geometrical and dimensional constraints.

The technological constraint for an operation is basically the precedent operation to be performed. For example, if a hole of diameter 12.5 mm is to be obtained, then we can have two operations viz. drilling and boring to get the finished hole. For operation boring, drilling is the technological constraint.

Dimensional constraint arises for a feature whenever its location is governed by another feature as a reference surface.

Geometrical constraint arises for a particular operation to get a particular feature whenever another operation constrains to get the required tolerance. For example, let there be a right angled step as shown in Fig. 3.5. If surface AB requires finish turning and AC requires facing and as per the instructions

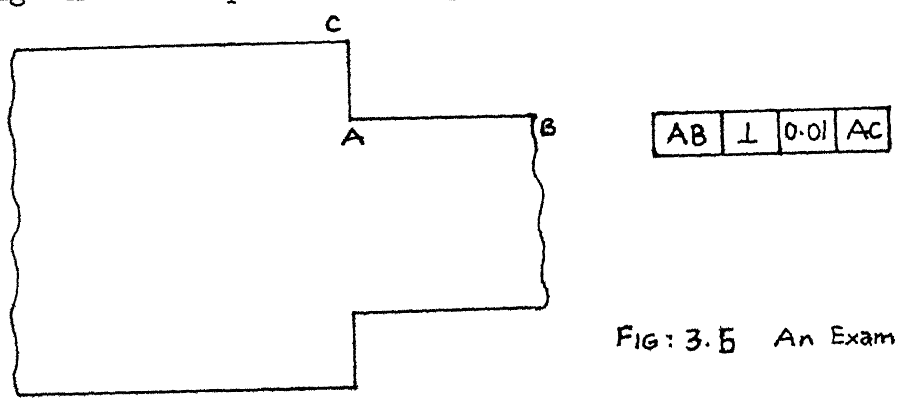


FIG: 3.5 An Example Part.

on the drawing i.e., $\boxed{AD \mid \perp \mid 0.01\text{ mm} \mid AE}$, facing is a geometrical constraint for turning (to obtain the specified perpendicularity of the two surfaces).

With these guidelines for identification of various constraints for each operation, the sequencing is carried out in the following manner [4].

<u>Step 1</u>: A table is prepared with various operations intended in the rows and the three constraints viz. technological, dimensional and geometrical, in the columns. For each operation, the corresponding constraints are identified and entered in the respective columns. This table is called Anteriority table. It is to be noted that the planner's knowledge of machining operations and technology plays a crucial role in preparing this table. It is also to be noted that if the entries to be made in the table are technically illogical, then it will lead to infeasible solution.

Step 2: Once the anteriority table is ready, a n x n matrix (n = no. of operations) called Anteriority matrix is prepared as follows. Here the rows and columns represent the intended operations in the same order. (Suppose if the 5th row corresponds to an operation K then 5th column of the matrix should also correspond to operation K). The entries in this matrix are made from the entries of the Anteriority table.

For example, for operation K if the constraining operations are P and Q then in the Anteriority matrix corresponding to the Kth row and Pth and Qth columns an entry (✓) is made. Similarly for all the operations the entries are made in the matrix.

Step 3: The above matrix is solved as follows. The number of entries made in each row of the anteriority matrix (which is nothing but the number of constraints that each operation has) is counted and stored in the first column of another matrix called Level Matrix. There will be always a row with zero level implying that it has no constraints at all. This is the first operation to be performed on the work part.

In the next iteration the rows and columns corresponding to the operation performed is deleted and fresh values of levels are recomputed and stored in the second column of the level matrix. The operation with zero level is identified and it is the next operation to be performed. This procedure is repeated until levels of all the operations become zero.

In case there is any discrepancy in preparing the anteriority table it will be reflected while solving the matrix resulting in infeasible solution.

(c) Time-Print Capsule:

Computes the machining time, non machining time, set-up time and hence the processing time for each operation. Also the total processing time for the part is evaluated. Once the processing time for each operation and the corresponding machine tool is known, from the machine occupancy ratio for each machine can also be computed. It is computed as follows.

$$\text{Occupancy ratio of Machine A} = \sum_i T_i \,/\, \text{Total processing time for the part}$$

where,

T_i = Processing time for the i-th operation on machine tool A.

3.2.2 Database Module:

The importance and role of database in CAPP has already been discussed in Chapter I. The technological data which is essential for generating a process plan are stored in a set of sequential files which forms the database of the CAPP-RP system. These files are basically files of records in which each record has many fields having one bit of data/information stored in them. The various files which are present in the CAPP-RP system are discussed below:

(a) Operations-Machine Tools File:

This file has operation code in one column and the corresponding machine tool code in the next column. The operation code for each operation is as shown in Table 3.2 and this information is flashed on the user's terminal while executing the program.

(b) Machine Tool Specifications File:

This file stores the specification of the machine tools that are present in the manufacturing system. The various information stored are machine tool code, status of machine tool (coded as MCUP), lower speed limit, upper speed limit, accuracy that it can achieve, lower feed limit, upper feed limit and economic batch quantity for processing. A section of the file is as shown in Table 3.3.

The machine tool name and the corresponding code are flashed on the user's terminal while executing the program. This is shown in Table 3.1.

(c) Operation - Cutting Tools File:

In this file the operation code and their corresponding cutting tool code are stored. The various cutting tools are given some identification code and the same is used in the operation - cutting tools file. In the CAPP-M system, it is assumed that each operation has a minimum of one tool but a maximum of three. A section of the file is as shown in Table 3.5.

(d) Cutting Tool Specifications File:

This has as many as three individual files for turning tools, drills and milling cutters.

The turning tool specifications file is described by the following information. They are individual tool code number, rake angle, relief angle, clearance angle and tool material. A section of the file is as shown in Table 3.6.

The drills specification file is described by the following features. They are individual tool code number, drill diameter, drill length, lip angle and tool material. A section of the file is as shown in Table 3.7.

The milling cutter specification file is characterized by the following features. They are individual tool code number, cutter diameter, cutter thickness and tool material. A section of the file is as shown in Table 3.8.

(e) Other Files:

These includes information pertaining to recommended speed and feed for counter boring, planeing, speed for threading,

Table 3.5: Operation code - cutting tool codes

Operation Code	Cutting tool code		
100	1	2	0
101	1	2	0
103	0	0	3
120	4	5	0
121	4	5	6
130	0	0	7
160	12	0	0
161	12	13	0
220	8	0	0
221	9	10	0
223	10	11	0
230	15	16	0
231	0	15	17
⋮	⋮	⋮	⋮

Table 3.6: Turning Tool Specifications.

Cutting Tool Code	Tool Specifications			
	Rake Angle	Relief Angle	Clearance Angle	Tool Material
8	5.0	20.0	4.5	TLSTEEL
9	7.0	10.0	5.0	CARBIDE
10	8.0	5.0	6.0	TLSTEEL
11	10.0	5.0	7.0	CARBIDE
.	.	.	.	.
.	.	.	.	.

Table 3.7: Drill Specifications.

Cutting Tool Code	Drill Specifications			
	Drill Dia. (mm)	Length (mm)	Lip Angle	Tool Material
4	15.0	45.0	20.0	CARBIDE
5	10.0	35.0	18.0	TLSTEEL
6	8.0	20.0	12.0	TLSTEEL
.	.	.	.	.
.	.	.	.	.

Table 3.8: Milling Cutter Specifications.

Cutting Tool Code	Milling Cutter Specifications		
	Diameter	Thickness	Tool Material
12	101.6	10.0	CARBIDE
13	76.2	7.5	TLSTEEL
14	50.2	5.0	CARBIDE
.	.	.	.
.	.	.	.

speed and feed for grinding operations.

(f) To Add/Delete a Record of Machine Tool Specification:

Whenever there is addition of another new machine tool to the system, the machine tool specification file will have to be updated. A new record with all theinformation of specifications of the new machine tool gets added to the file by a program.

Similarly, if any of the machine tool is unavailable for machining purposes, another program makes one of the key field (viz. MCUP) zero thus implying that it is unavailable. And another program converts the unavailable machine tool into available one by changing its status (viz. changing MCUP from 0 to 1).

The details of data structures used in the design of the database is discussed in detail in Chapter IV.

3.3 SYSTEM DESIGN:

The system is designed to perform the following activities:

(i) Performs coding and classification of the part.

(ii) Checks for a matching partfamily for the part in question. If matching part family is present, retrieves the plan code and the plan.

(iii) Otherwise, employs generative technique. For a specified set of operations, selects the machine tool based on accuracy and minimum machining cost as criterion. Also determines optimum speed and feed.

(iv) Retrieves a cutting tool and its specification from DB for all operations based on required tool material as criterion.

(v) Sequences operations taking into account constraints like dimensional, geometrical and technical.

(vi) Computes various times like machining time, non machining time, processing time etc. and calculates the cost of machining the parts.

System flow chart of CAPP-RP is as shown in Fig. 3.1.

CHAPTER IV

IMPLEMENTATION DETAILS

The implementation of the designed CAPP-RP system has been done on DEC-1090 computer system in PASCAL language. Programs written is partly interactive in nature. Due to a large amount of data to be fed in as input it was felt that it would be advantageous to evolve the plan interactively on a CRT terminal. This would also avoid infeasible results due to wrong input, though it is time consuming. Another advantage is that if the database is very big then the CAPP-RP system needs interaction of the user to make decision regarding the data retrieved.

The complete software is divided into two parts. They are source program, and database programs. The details of each are given below.

4.1 SOURCE PROGRAM:

The source program is the one corresponding to planning module of the system. This has a number of procedures some of which are called in the main program and some other in sub-programs. The major procedures of the source program are explained below.

4.1.1 <u>Coding of Parts (Procedure CODE)</u>:

This procedure codes and classifies a rotational part based on its geometric, design and manufacturing attributes. The output of this procedure is a ten digit code representing the part code. The coding of parts is done interactively on a CRT terminal answering a set of quaries representing the part's attributes.

4.1.2 <u>Part Family Checking (Procedure PFAMLYCHK)</u>:

The input for this procedure is the part code generated by procedure CODE. This procedure checks whether the code generated has a matching part family code for which a process plan is already available. If there is one, the process plan code is retrieved from which the plan can be retrieved. Otherwise, it calls in another procedure to generate the plan.

4.1.3 <u>Generative Planning (Procedure GENERATIVE)</u>:

This procedure indicates the operation capability of the system and also the corresponding operation code for each operation. These codes are used in all subsequent evaluation. And for each intended operation this procedure calls others for the selection of machine tools and cutting tools.

4.1.4 <u>Machine Tool Selection (Procedure MCTLSEL)</u>:

For every intended operation this procedure gives a list of machine tools capable of performing the operations, their specifications and aids in the selection of suitable machine tool. To evaluate the optimum speed and feed and hence the

machining cost it calls in another sub-program called procedure OPTIMIZE.

4.1.5 Optimization of Speed and Feed (Procedure OPTIMIZE):

For every operation, it finds out the optimum speed and feed and hence the optimum machining cost. This procedure has a number of procedures and functions that are called in turn.

4.1.6 Cutting Tool Selection (Procedure CUTOLSEL):

This procedure retrieves the possible cutting tools for each operation from the DB and selects one of them.

4.1.7 Operations Sequencing (Procedure SEQUENCE):

The operations are sequenced into technically a logical order by this procedure.

4.1.8 Printing Process Plan (Procedure PRINTIME):

This procedure calculates the various times for each operation and prints the plan in a neat format.

4.2 DATABASE PROGRAMS:

The database for technological data is created by the following set of programs.

4.2.1 Operations and Machine Tools (Program INFIL):

This program creates a sequential file of records in which each record has three fields. The first is serial number, then operation code and the corresponding set of machine tools codes capable of performing the operation.

4.2.2 Machine Tool Specifications (Program STFIL):

This program creates a sequential file of records in which the fields are defined by MCUP (to indicate whether the machine tool is up or down, 0 if down and 1 if up), machine tool code, (a unique integer), minimum speed (in rpm), maximum speed (in rpm), feed low (mm/revolution), feed high (mm/revolution), accuracy (mm) and economic batch quantity in that order.

The relationship between file INFIL and file STFIL is as shown in Fig. 4.1.

4.2.3 Operations and Cutting Tools (Program CUTOLFIL):

This program creates a sequential file of records in which the fields are defined by serial number, operation code, an array of cutting tool code and another field called limit to denote for which operation that particular tool can be used.

A sample file CUTOLFIL is as shown in Fig. 4.2a.

4.2.4 Turning Tool Specifications (Program TRTLFIL):

This program creates a sequential file of records in which the fields denote serial number, a cutting tool code number, rake angle, clearence angle, relief angle and a packed array of characters of tool material in that order. This is exclusively for turning tools. A sample data structure is as shown in Fig. 4.2b. The relationship between file CUTOLFIL and file TRTLFIL is shown in Fig. 4.2a and 4.2b.

4.2.5 Drills Specifications (Program DRFIL):

This program creates a sequential file of record in which the fields are defined as serial number, cutting tool code number,

Operation Code	M/C Tool Code		
A	$\boxed{p}$	$\boxed{q}$	$\boxed{r}$
B	.	.	.
:	:	:	:

M. OP	M/C Tool Code	Speed (min)	Speed (max)	Power (KW)	Accuracy	Feed (min)	Feed (max)	EBQ
1	p	-	-	-	-	-	-	-
1	q	-	-	-	-	-	-	-
1	r	-	-	-	-	-	-	-

Fig. 4.1: Data structure of file IMFIL and file STFIL.

Operation Code	Cutting Tool Code		
B	l	m	n
C	o	p	q
D	i	j	k
:	:	:	:

Fig. 4.2a: Data structure of file CUTOLFIL.

Cutting Tool Code	Rake Angle	Clearance Angle	Relief Angle	Tool Materi
l	–	–	–	–
m	–	–	–	–
n	–	–	–	–
:	:	:	:	:

Fig. 4.2b Data structure of file TRTLFIL.

drill diameter, drill length, lip angle and tool material in that order.

A sample data structure is shown in Fig. 4.2c and the relationship between the file CUTOLFIL and file DRFIL is also shown.

4.2.6 Milling Cutter Specifications (Program MIFIL):

This program is for the creation of a sequential file of records in which the fields are defined as serial number, cutting tool code number, cutter diameter, cutter thickness and tool material in that order. A sample data structure is shown in Fig. 4.2d and the relationship between file CUTOLFIL and file MIFIL is also shown.

4.2.7 Part Family and Plan Codes File (Program PFIL):

This program creates a sequential file of records in which the fields are defined as serial number, part family code and corresponding plan code in that order.

A sample data structure is shown in Fig. 4.3.

4.2.8 Speed and Feed Tables for Counter Boring (Program CBORE 1, Program CBORE 2):

A sequential file of records is created to store the recommended speed and feed for counterboring operation.

In speed table, the field are in the following order: material code, lower speed and maximum speed.

In the feed table, fields are in the following order: lower diameter, higher diameter, lower feed and high feed.

Operation Code	Cutting tool Code		
[illegible]	l	m	n
[illegible]	o	p	q
[illegible]	i	j	k
:	:	:	:

Fig. 4.2a: ACTOLFIL

Cutting Tool Code	Drill Dia.	Drill	Lip Angle	Tool Materi
o	–	–	–	–
p	–	–	–	–
q	–	–	–	–
:	:	:	:	:

Fig. 4.2c: Data structure of file DRFIL.

Cutting Tool Code	Cutter Dia	Cutter thick-ness	Tool Material
i	–	–	–
j	–	–	–
k	–	–	–
:	:	:	:

Part family code	Process plan code
1234567890	100
1234455560	101
.	.
.	.

Fig. 4.3e: Data structure of file PFIL.

4.2.9 Speed and Feed Tables for Planeing (Program PLANFIL):

This creates a sequential file of records in which the fields are defined as depth of cut, recommended feed and speed values in that order.

4.2.10 Speed Table for Threading (Program [illegible]):

This program creates a sequential file of records in which the fields are thread diameter, lower pitch, higher pitch, and speed to be employed along with number of cuts in that order.

4.2.11 Speed-Feed for Grinding (Program GRIFIL):

This program is used to create a sequential file of records in which each record has the following fields. They are lower value of work diameter, higher value of work diameter, work speed (in rpm) and feed (mm/revolution) in that order. A sample data structure is shown in Fig. 4.4.

4.2.12 To Add a Record of Machine Tool Specification (Program ADD)

This program adds a new record of machine tool specification to the already existing specification file, whenever a new machine tool is acquired. It also makes the corresponding changes in the file INFIL (operations - machine tool file) for the operations which the new machine tool is capable of performing.

4.2.13 To Delete a Record of Machine Tool Specification (Program DELREC):

This program deletes a record i.e. makes a record passive in the machine tool specification file (STFIL) by making a key field (field MCUP) zero. This ensures that this machine tool is not available for machining for reasons of breakdown/maintenance/ overload

Lower work Dia. (mm)	Higher work Dia (mm)	Work speed (rpm)	Feed (mm/revolution)
10.0	25.0	450.0	0.75
.	.	.	.
.	.	.	.
.	.	.	.

Fig. 4.4: A sample data structure of file GRIFIL.

CHAPTER V

TEST RUNS AND ANALYSIS

To test the developed CAPP-RP system, several example parts were taken and process plan for the same were generated. The details of test runs are explained in the following paragraphs.

The details of part design specifications, drawing and other required input data for generating the process plan are as follows. Four rotational parts comprising different operations and features are chosen and tested. The results obtained i.e. the process plan for each part is given in Appendix A. It is also shown, how the already generated process plan can be altered whenever any machine tool selected for any of the operations becomes unavailable due to breakdown, maintenance or loaded with a high priority jobs etc. Both categories of process plan are generated for the same input.

<u>Example 1</u>:

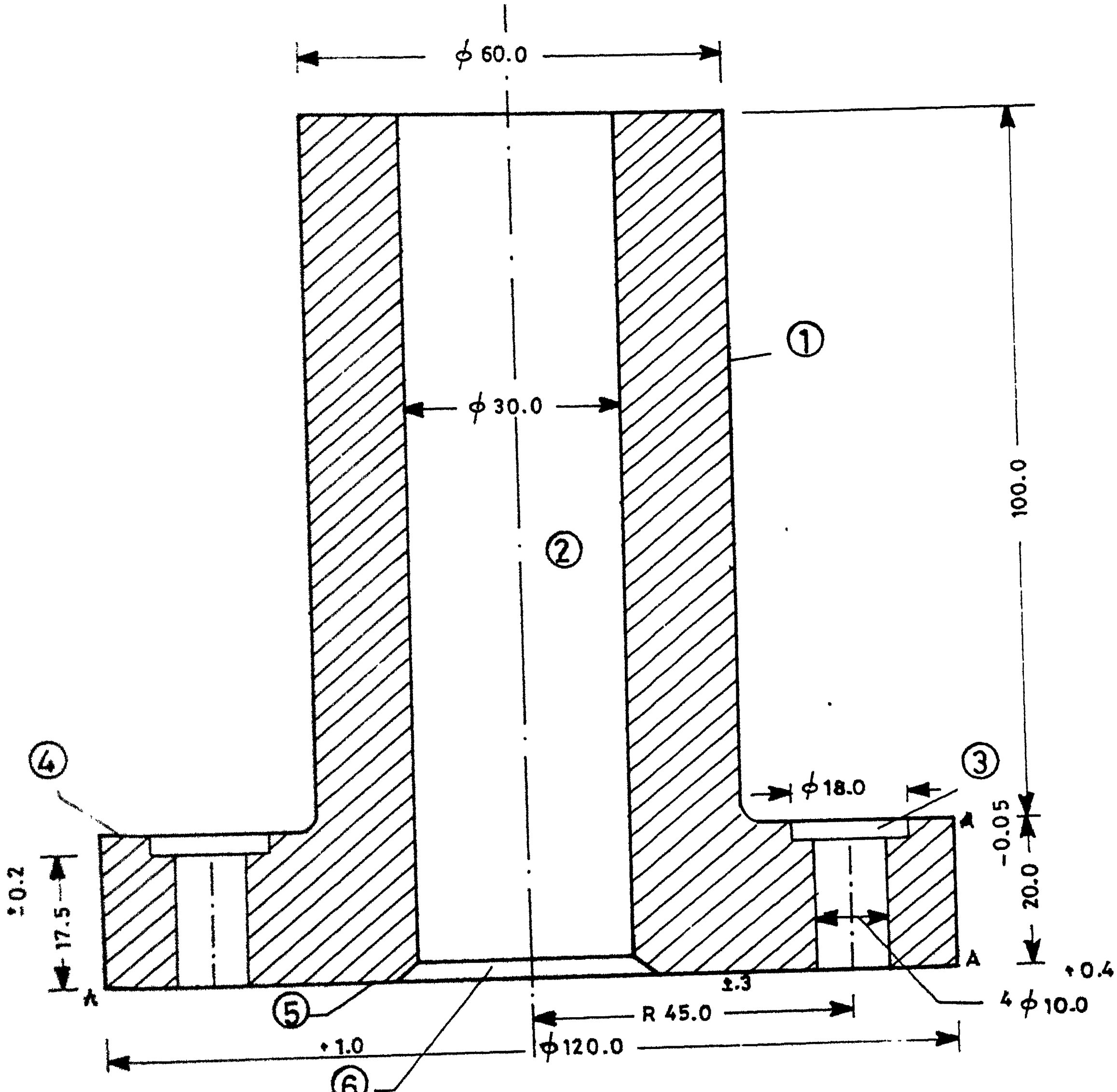
The part under consideration is as shown in Fig. 5.1. Apart from the design specifications the following input data are also taken into account. Table 5.1 gives the feature number marked in Fig. 5.1 and corresponding operation code employed.

Table 5.1: Feature No. - Operation Code Used Table.

Feature No.	Operation Code Used
1.	2201, 2221
2	1201
3	120, 103
4	2312
5	2301, 2311
6	240

Work material. Cast Iron
Quantity. 1000 nos.

3	⊥	φ 0.02	5



SCALE: 1:1
ALL DIMENSIONS IN M.M

Fig . 5.1

Ps. ⊥-Denotes perpendicularity of two surfaces

Machine tool:

Efficiency of Machine tool = η_m = 0.9

Maximum force acting during cutting on any machine tool = F_{cu} = 150.0 Kgf (finish facing operation)

= 200.0 Kgf (rough facing operation)

= 250.0 Kgf (all other operations)

Cutting tools:

Tool cost/cutting edge = C_t = Re. 1.00 (For all tools)

Tool changing time = T_c = 0.75 min. (for drills and facing tools)

= 0.50 min. (for all others)

Minimum tool life for all tools = T_1 = 10.0 min.

Work Material: Cast iron

Constants C_1 = 35.0,

C_2 = 0.4 Equation for F_c in Table A-1.

Production Data:

Operating cost/min = C_o = Rs. 0.40/min (Drilling and facing operation)

= Rs. 0.10/min (All other operations)

Handling time/piece = T_p = 2.5 min. (Drilling and facing operation)

= 2.0 min. (All other operations)

Batch size = 1000 nos.

Apart from the above data, the anteriority table required for sequencing of operations is as shown in Table 5.2. Explanation for some of the entries made in the anteriority table is as follows.

Table 5.2: Anteriority Table.

Description of operation	Operation Code	Dimensional	Geometrical	Technological
Drilling of hole of diameter 25.0 mm	1201	-	-	-
Rough facing of the end with 120.0 φ	2301	2312	-	-
Finish facing of the end which is 120.0 in dia.	2311	2312	-	2301
Counterboring of hole dia 16.0 mm to 18.0 mm	103	2311	-	120
Drilling of hole dia 16.0 φ	120	2221	2312	-
Rough turning of the cutter outer surface length = 120.0 mm	2201	1201	-	-
Finish turning of the outer surface L = 120.0	2221	240	2311	2201
Chamfering at the end of hole 25.0 φ	240	2311	-	-
Finish facing at end BB	2312	2201	-	-

Drilling of 10.0 mm diameter hole has operation, finish turning (2221) as dimensional constraint since the centre of the hole is measured from the end marked AA in Fig. 5.1. Finish facing (2312) is the geometrical constraint because the angle between the axis of the hole and the finished face should be within the specified limits.

Counterboring (103) of the hole of diameter 15.0 mm has drilling (120) as the obvious technological constraint since counter boring can not be done before drilling. Finish facing of the end (2311) is the dimensional constraint as it is the reference surface for deciding the height of the hole.

So far the basic essential inputs for generation of process plan are discussed. And the output of this exercise is as shown in Appendix B-1.

Exercise 2:

The part drawing is as shown in Fig. 5.2. The Table 5.3 indicates the feature number marked in Fig. 5.2 and the corresponding operation codes employed. The work material was taken as cast steel with initial blank shape corresponding to the final shape but with 5 mm of extra material throughout. The length of the blank was taken as 140.0 mm as against the finished part length of 130.0 mm.

Apart from design specification the following data are also taken for evaluation of various paremeters minvolved.

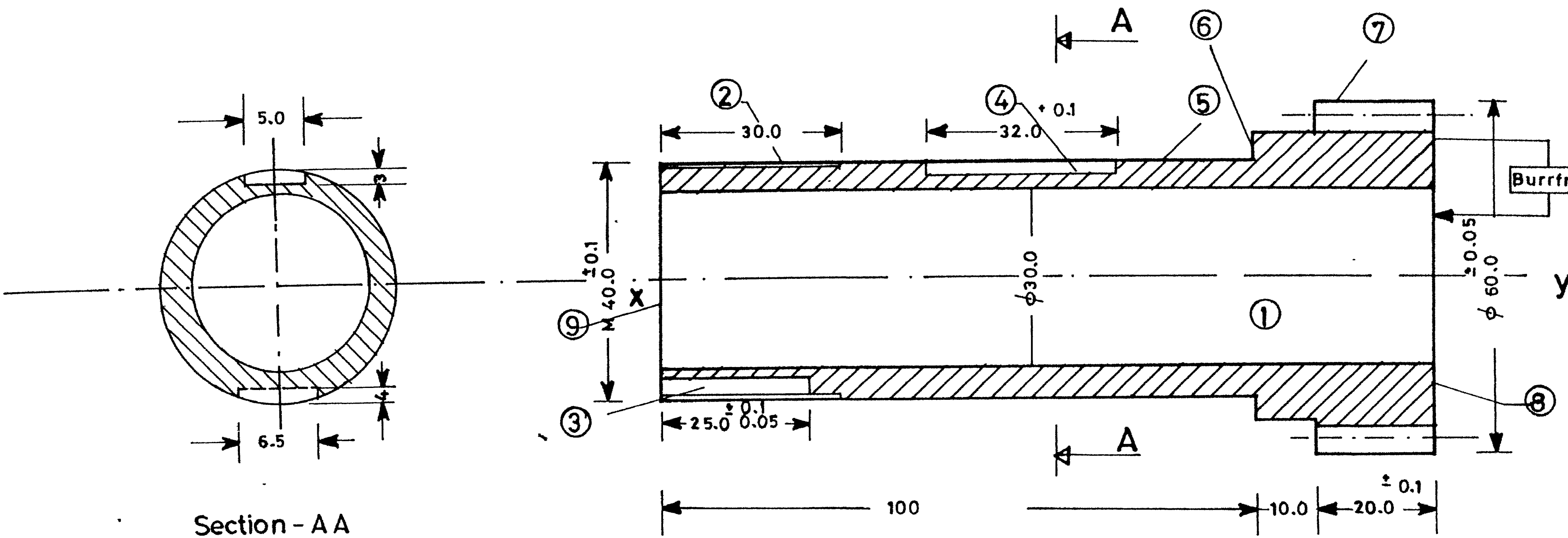
Table 5.3: Feature No. - Operation Code Used Table.

Feature No.	Operation Code Used
1	1201, 1202, 101
2	200
3	1601
4	1602
5	2201, 2221
6	2313
7	161
8	2302, 2312
9	2301, 2311

No. OF TEETH	24
MODULE	
PRESSURE ANGLE	20°
TOOTH DEPTH	4.47

Work material. Cast Steel
Quantity. 1200 nos.

5	⊥	ϕ 0.01	6
3	∠	$\pm 0.5^{\circ}$	4



SCALE : 1:1
ALL DIMENSIONS IN M.M.

Fig. 5.2

ps. ⊥ - Perpendicularity , ∠ - Angularity

Machine tools:

Efficiency of machine tool $= \eta_m = 0.9$

Maximum force acting during cutting on any machine tool $= F_{cu} = 400.0$ kgf (for all operations)

Cutting tools:

C_t = Rs. 1.00/edge

T_c = 0.5 min

T_1 = 10.0 min

Work material: Cast Steel.

Value of constants $C_1 = 35.0$ and

$C_2 = 0.25$ (Eq. 1 in Table A.1)

Production data:

C_o = Rs. 0.10/min

T_p = 2.0 min/piece,

Batch size = 1200 nos.

The other data required is anteriority table which is as shown in Table 5.4. Explanation for some of the entries made in the table is as follows.

For example, the slot milling operation (1601) has finish facing of end (2311), slot milling (1602) and finish turning (2221) as dimensional, geometrical and technological constraints respectively. It is so, because, only after finish facing (2311) of the end X it is possible to fix the length of the slot as per design specifications. Hence finish facing of end X (2311) is the dimensional constraint for slot milling (1601). Similarly slot milling (1602) poses geometrical constraint on (1601)

Operation name/Description	Operation Code	Dimensional	Geometrical	Technological
Boring of hole 26.0 φ	101	-	-	1202
Drilling of hole 20.0 mm, length 135.0 mm	1201	-	-	-
Drilling of 25.0 mm hole L = 135.0 mm	1202	-	-	1201
Slot Milling L = 25.0mm B = 4.0mm W = 6.5mm	1601	2311	1602	2221
Slot Milling L = 32.0 mm B = 3.0 mm W = 5.0 mm	1602	2311	200	2221
Gear Milling Outer diameter 51.94 mm Width = 20.0 mm	161	2312	-	2221
Thread Cutting L = 30.0 mm D = 35.0 mm	200	2313	-	2221
Rough turning on outer surface: L = 135.0 mm	2201	2312	101	-
Finish turning on outer surface L = 135.00 m	2221	-	-	2201
Rough facing of end A Dia. 35.0 mm	2301	-	101	-
Rough facing of end B Dia. 51.94 mm	2302	2311	-	-
Finish facing of end A Dia. 35.0 mm	2311	-	-	2301
Finish facing of end B Dia. 51.94 mm	2312	-	-	2302
Finish facing of step, Dia. 45.0 mm	2313	161	2221	-

Table 5.4: Anteriority Table.

higher processing cost (because for selection of machine tool minimum machining cost is the criteria). It is also observed that the newly generated plan has lower processing time than the original one. This may be attributed to the fact that machining time is not considered as a criteria for machine tool selection. Also, it may be due to the reason that the cheapest machine tool takes longer processing time.

Example 3:

The part under consideration for study is as shown in Fig. 5.3. Table 5.5 gives the feature code marked in Fig. 5.3 and the corresponding operation code employed. Apart from design specifications the following data are also taken.

Machine tool:

Efficiency of machine tool $= \eta_m = 0.9$

Maximum cutting force on any machine tool $= F_{cu} = 300.0$ kgf(for finish facing operat

$= 400.0$ kgf(all other operations)

Cutting tools:

C_t = Re 1.00/edge (for all tools)

T_c = 0.5 min

T_l = 10.0 min (all tools)

Work Material: Mild Steel Rod

Constants C_1 = 50.0

C_2 = 0.15 (Eq.1, Table A.1)

Production data:

C_o = Rs. 0.10, T_p = 2.0 min.

Batch size = 1500 nos.

Work material Mild Steel
Quantity 1500 nos

2	⊥	0.01	4
3	∠	0.05	9
6	○	0.01	9

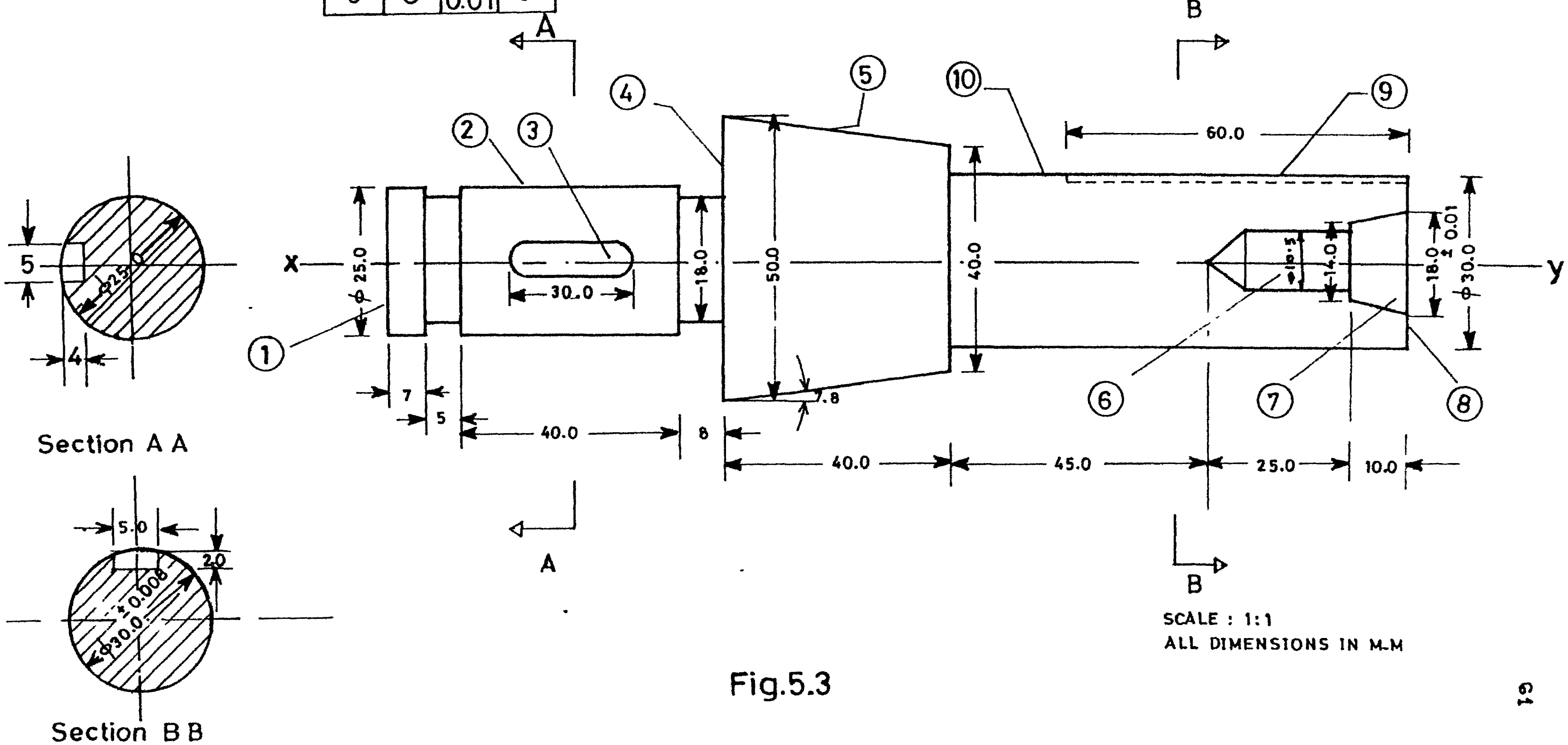


Fig.5.3

ps. o - Circularity, ⊥ - Perpendicularity, ∠ - Angularity

Table 5.5: Feature No. - Operation Code Used Table.

Feature No.	Operation Code Used
1	2302, 2312
2	2203, 2221
3	160
4	2313
5	223
6	120, 101
7	250
8	2301, 2311
9	162
10	2201, 2202, 2222

Anteriority table for the part is as shown in Table 5.6. The explanation for some of the entries made in the table is as follows.

For drilling a hole of 10.5 mm diameter, the drawing specifies that the circularity of the hole with reference to the outer cylindrical surface must be maintained. Hence, it calls for proper centring of the hole. Hence operation finish turning (2222) is done prior to drilling, (viz. (2222) is a geometrical constraint for (120)). Finish facing of end B(2311) poses dimensional constraint because the hole length is measured from the end B which requires finish facing.

Operation, keyway milling (162) has finish facing of end B (2311) from which the length of keyway is established as dimensional constraint. Slot Milling (160) poses geometrical constraint to keyway Milling (162) because the 2 slots should be oriented at right angles to each other. And finish turning (2222) is the technological constraint to keyway Milling (162) since keyway can not be cut before finish turning.

With the above input, the program is run to generate the plan and resultant process plan is as shown in Appendix B-4).

<u>Example 4:</u>

The part under consideration is a combination of the previou two parts along with one more feature i.e. external splines. The part drawing is as shown in Fig. 5.4. Table 5.7 gives the list of feature code marked in Fig. 5.4 and the corresponding operation

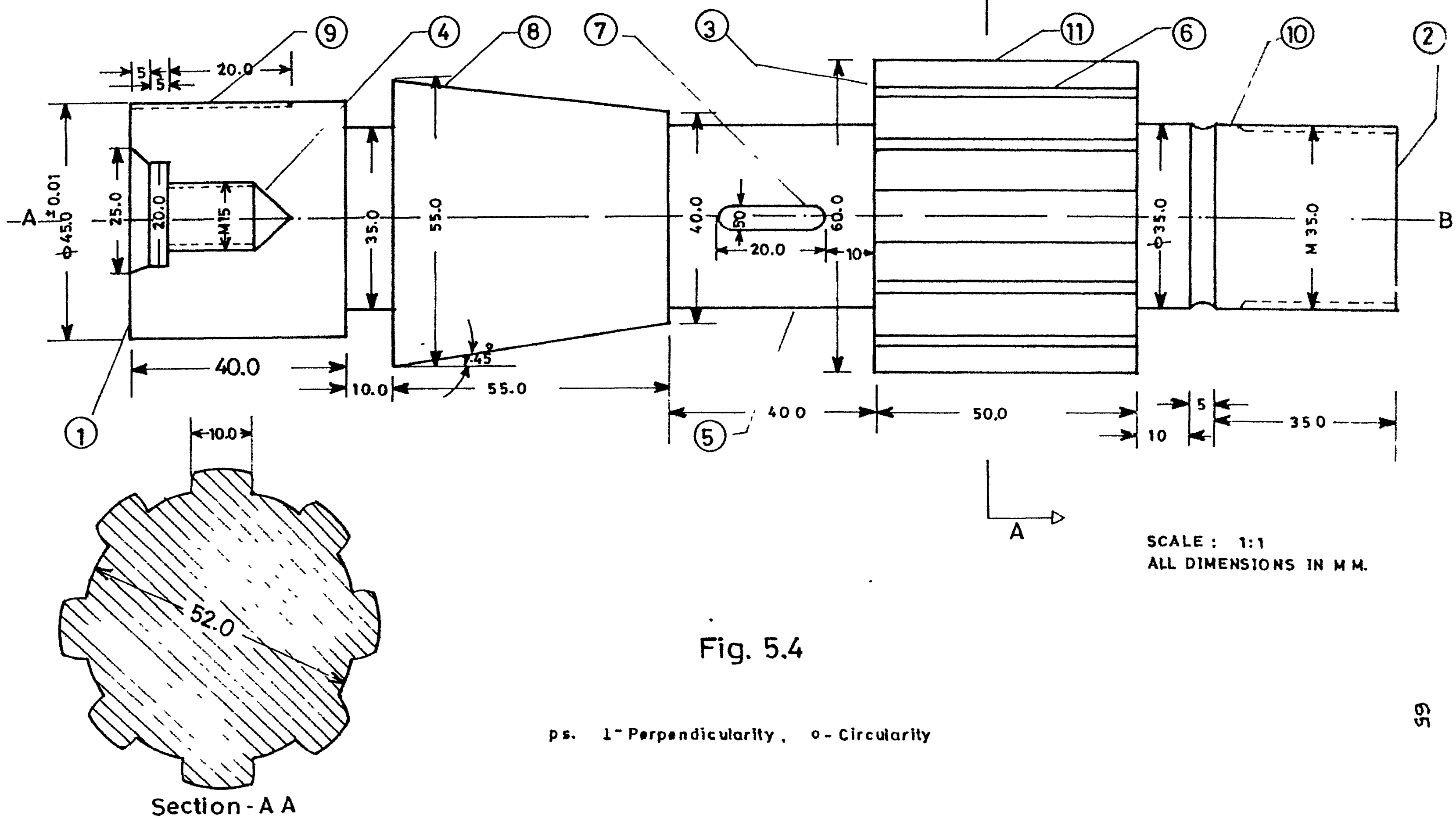
Table 5.6: Anteriority Table.

Operation name/ Description	Operation Code	Constraints: Dimensional	Constraints: Geometrical	Constraints: Technological
Drilling of hole 10.5 mm dia., 40 mm length	120	2311	2222	-
Rough facing of end Y dia. 24.0 mm.	2301	2312	-	-
Rough facing of end X dia. 20.0 mm.	2302	-	-	-
Finish facing of end Y dia. 24.0 mm.	2311	-	-	2301
Finish facing of end X dia. 20.0 mm.	2312	-	-	2302
Finish facing of taper end dia. 350.0 mm.	2313	2312	2221	223
Counter sinking 13.0 mm dia. - 18.0 mm dia. L = 10.0 mm.	250	2311	-	120
Slot milling L = 30.0 mm, W = 5.0 mm, d = 4.0 mm.	160	2313	-	2221
Boring of hole 10.5 mm. dia., L = 40.0 mm.	101	250	-	120
Key way milling L = 60.0 mm, W = 5.0 mm. D = 2.0 mm.	162	2311	160	2222
Rough turning from end Y to taper L = 120.0 mm. D = 35.0 mm.	2201	2311	-	-
Rough turning from end Y to taper edge L = 120.0 mm, D = 30.0 mm.	2202	-	-	2201
Rough turning from end X to taper edge L = 60.0 mm, D = 30.0 mm.	2203	101	-	-
Finish turning from end X to taper edge L = 60.0 mm, D = 25.0 mm.	2221	223	-	2203
Finish turning from end Y to taper edge L = 90.0 mm. D = 24.0 mm.	2222	2311	-	2202
Taper turning $D_1 = 50.0$ mm, $D_2 = 40.0$ mm. $\alpha = 7.8^{\circ}$	223	2311	-	2203

Work material Mild Steel
Quantity 1500 nos

7	⊥	0.05	9
5	⊥	0.01	11

3	⊥	0.01	5
4	O	0.01	5



SCALE : 1:1
ALL DIMENSIONS IN M M.

Fig. 5.4

ps. ⊥ - Perpendicularity , o - Circularity

Table 5.7: Feature No. - Operation Code Used Table.

Feature No.	Operation Code Used
1	2301, 2311
2	2302, 2312
3	2313
4	120, 103, 240, 130
5	2201, 2221
6	163
7	161
8	223
9	250
10	200
11	130

codes employed. The following data are also taken into account apart from design specifications.

Machine Tools:

η_m = 0.9

F_{cu} = 350.0 kgf (for Finish facing operation)
400.0 kgf (for Rough facing operation)
425.0 kgf (all other operations)

Cutting Tools:

C_t = Rs. 1.00/edge

T_c = 0.5 min (facing tools)
0.75 min (other tools)

T_1 = 12.0 min

Work Material: Mild Steel rod

Constants C_1 and C_2 are 45.0 and 0.3 respectively (Eq. 1, Table A.1).

Production Data:

C_o = Rs. 0.40 (Facing, Milling)

T_p = 2.0 min (Facing)
2.5 min (others)

Batch Size = 1500

Explanation for some of the entries made in the anteriority Table 5.8 is as follows.

Counterboring (103) has tapping (190) as geometrical constraint and drilling (120) as technological constraint. viz. to say counterboring is done after tapping to obtain the required sharp

Table 5.8: Anteriority Table.

Operation name/ Description	Operation Code	Constraints Dimensional	Geometrical	Technological
Rough facing of end A D = 45.0 mm.	2301	2312	-	-
Rough facing of end B D = 35.0 mm.	2302	-	-	-
Finish facing of end A D = 45.0 mm.	2311	-	-	2301
Finish facing of end B D = 35.0 mm.	2312	-	-	2302
Rough turning of the outer surface, L = 280 mm.	2201	2311	-	-
Finish turning of the outer surface, L = 280.0 mm.	2221	223	-	2201
Taper turning, D_1 = 55.0 mm. D_2 = 40.0 mm, $\alpha = 7.45^{\circ}$	223	-	-	2201
Counter boring, D = 20.0 mm. L_1 = 5.0 mm.	103	-	190	120
Drill hole of 15.0 mm, L = 30.0 mm.	120	2313	2221	-
Counter sinking D_1 = 25.0 mm, D_2 = 20.0 mm L = 5.0 mm.	240	103	-	120
Thread (Internal) cutting M15.0 mm, L = 20.0 mm.	190	-	-	120
End Milling of Slot L = 30.0 mm. W = 5.0 mm. d = 4.0 mm.	161	2313	250	2221
Spline Milling, W = 10 mm, d = 4.0 mm.	163	161	-	2221
Keyway shaping, L = 30.0 mm, W = 3.0 mm, d = 1.5 mm.	250	240	-	2221
Thread (External) cutting M35.0 mm, Pitch 1.5 mm.	200	163	-	2221
Finish grinding of splines	130	200	-	2221
Finish facing of the edge face of splines. D = 60.0 mm.	2313	2311	2221	-

edge at the interaction of threads and enlarged hole. Otherwise, the internal thread cutting operation may spoil the edge of the hole. Drilling (120) is the technological constraint because counter boring can be done only after drilling.

Slot Milling (161) has keyway shaping (250) as geometrical constraint because the alignment of slot and keyway should be achieved as per design specifications (viz. 90 $\pm^{20}$). End facing (2313) of splines is dimensional constraint since the slot dimensions are decided by that face. And finally, finish turning (~~221~~ (2221) is the technological constraint.

The other entries are made as per the requirements and demands of each operation.

With this set of input, the program is run and the resultant process plan obtained is as shown in Appendix B-5).

The variation of the above problem gives us another plan when one of the selected machine tool for any of the operations is made unavailable. The program is rerun for the same input to get the modified process plan which is as shown (App. B-6).

It is once again observed that the total machining cost for the part in the modified plan is more than the original plan. It is also observed that the processing time is lower than that of original one.

CHAPTER VI

SUMMARY

In this chapter, the conclusions for the present work and suggestions for future development are presented.

6.1 CONCLUSIONS:

The designed CAPP-RP system is partly interoctive in nature. In this system, the coding of parts is done interoctively on a CRT terminal answering a set of quaries describing parts attributes. The source program of the system in conjunction with engineering database synthesizer the process plan. The process plan output comprises operations sequence, machine tool selected, Machinability Data Systems (optimum speed and feed for cutting), machining time, totel processing time and machining cost also.

The system is capable of generating process plans efficiently for different types of rotational parts. It is also capable of generating alternate plan when one of the machine tools becomes unavailable (due to breakdown, maintenance or loaded with high priority job). This feature of the system helps the planner/user in FMS environment to generate alternate plans in real time. The system is capable of generating process plans for wide variety of parts requiring large number of operations to be performed. It has been tested for parts requiring as many as 17 operations.

6.2 SUGGESTIONS FOR DEVELOPMENT:

The present system can be made more comprehensive by incorporating the following improvements.

(i) Interfacing with a comprehensive DBMS: As alreadym mentioned, the system makes use of a set of sequential files with some programs to add and delete the records from these files. Interfacing the system with a commercially available more comprehensive DBMS package will impart more program flexibility to the system.

(ii) Developing an intelligent procedure for the selection of process: Presently, the selection of processes is being done by the planner/user. The suggested procedure should select the suitable operations based on part code generated.

(iii) Developing an intelligent procedure for operations sequencing: The important step of preparing the anteriority table in operations sequencing is done by the planner/user. The suggested procedure should identify the type of constraint and also the constraining operations that each operation has.

It is observed that most of the process planning activities are not quantifiable. Hence it is suggested that the future emphasis should be in the application of AI techniques like Expert Systems which are basically rule drivens.

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APPENDIX A

SOLUTION PROCEDURE FOR OPTIMIZATION MODEL

As already discussed in Chapter III the optimal values of speed and feed can be obtained by solving the following optimization problem. With minimization of total machining cost as criteria, the objective function (Z) is writte as,

Minimize

$$Z = n\, C_o\, t_m + n\, t_m\, C_t/T_1 + n\, t_m\, T_c\, C_o/T + C_o\, T_p$$

and constraints set is

Bounds on speed : $V_l \leq V \leq V_u$

Bounds on feed : $f_l < f \leq f_u$

Bounds on Power : $P \leq P_{in} \eta_m$

Bounds on Torque : $T_d \leq T_{alow}$

Bounds on Tool life: $T_1 \leq T$

It is observed that the objective function is a function of machining time (t_m) and tool life (T) which in turn are function of speed and feed of cutting as it is evident from the relations of t_m and T for various operations as given in Table A.1. These operations include turning, drilling, milling, gear milling and facing. The objective function and as well as the constraints set can be rewritten by substituting the expressions for t_m, T, P, F_c and T_d for respective operations.

For example, turning operation, the objective function takes the form,

Minimize,

$$Z = \frac{n\, C_o\, \pi\, D\, L}{1000 . V . f} + \frac{n . \pi . D . L}{1000} . \frac{V^{\alpha_1 - 1}\ f^{\alpha_2 - 1} . d^{\alpha_3}}{\alpha}$$

$$[\, C_t + T_c + C_o \,] + C_o . T_p$$

and constraints are:

$$V_l \leq V \leq V_u$$

$$f_l \leq f \leq f_u$$

$$F_c \leq F_{cu}$$

$$P \leq P_{in} . \eta_m$$

$$T_l \leq T$$

where,

cutting force during turning F_c is given by [9]

$$F_c = \frac{d . f . \cos(\eta - \gamma)}{\cos(\beta + \eta - \gamma) \sin \beta} \quad [30.3\ C_2^{0.035}\ V^{0.07} - 0.0105 . C_1 .$$

kg

According to Shaffer, the value of $(\beta + \eta - \gamma)$ can be taken as $\pi/4$ [12] and hence

$$\frac{\cos(\eta - \gamma)}{\cos(\beta + \eta - \gamma) \sin \beta} = 1 + \cot \beta = 1 + \frac{K - \sin \gamma}{\cos \gamma}$$

where K is the chip reduction coefficient and is given by [9],

$$k = 0.9 \left[\frac{1 + x}{\sqrt{(1 - x)^2 + x}} \right] + 0.7$$

with $x = \left(\frac{V.e^{2.21}\ f}{142.0} \right)^2$

The values of C_1 and C_2 are constants for any particular work material.

$$\text{Power } (P) = \frac{0.746.\ F_c.V}{4500.0} \quad \text{kw}$$

and $T = \alpha / V^{\alpha_1} f^{\alpha_2} d^{\alpha_3}$

where α, α_1, α_2 and α_3 are constants for any work material.

The above optimization problem is solved as follows. It is observed that the nature of the objective function and constraints is nonlinear due to the presence of exponential and trigonometric terms. Hence it is solved as a nonlinear minimization problem. To do so, the problem is first converted into a unconstrained minimization problem by interior penalty function technique.

Penalty function methods transform the original optimization problem into alternative formulations such that numerical solutions are sought by solving a sequence of unconstrained optimization problem.

For example,

Find $X = (x_1, x_2, x_3, \ldots, x_n)$ which

Minimizes $f(x)$ subject to

$$g_j(X) \leq 0, \quad j = 1,2,\ldots, m \tag{1}$$

This is converted into an unconstrained minimization problem by constructing a function of the form

$$\phi_k = \phi(X, r_k) = f(X) + r_k \sum_{j=1}^{n} G_j [g_j(X)]$$

where G_j is some function of the constraint g_j and r_k is a positive constant known as penalty parameter. If the unconstrained minimization of ϕ function is repeated for a sequence of values of penalty paramter the solution may be brought to converge to that of original problem stated in (I).

In our case, interior penalty method is chosen and the form of G_j is as follows.

$$G_j = - \frac{1}{g_j(X)}$$

and hence

$$\phi_k = \phi(X, r_k) = f(X) - r_k \sum_{j=1}^{m} \frac{1}{g_j(X)}$$

The converted problem is then solved by Powel's method (basically a pattern search method) or Davidon Fletcher Powel (DFP) method (basically a steepest descent method making use of derivatives of the function). These two methods are employed in order to take care of both quadratic and nonquadratic nature of the objective function and construints set which keeps changing from operation to operation.

Powel's method of solving unconstrained minimization for quadratic functions is found to be very good than other methods [15] This method will minimize a quadratic function in a finite number of steps since it is proved that this is a method of conjugate directions [15]. The various steps in solving a unconstrained minimization problem by Powel's method is shown in flow chart.

method is the best general purpose unconstrained optimization technique making use of currently available derivatives of the function. This method is very powerful and converges quadratically (since it is a conjugate direction method). It is very stable and continues to progress towards the minimum even while minimizing eccentric functions. The stability of this method is attributed to the fact that it carries the information obtained in previous iterations through the Hessian matrix. The iterative procedure of this method can be stated as follows:

(i) Start with initial values of speed and feed and a 2 x 2 positive definite symmetric matrix H_i, which is taken as a identity matrix I. Set iteration no. i = 1.

(ii) Compute the gradient of the function, ∇f_i at the point X_i and set

$$S_i = -H_i \cdot \nabla f_i$$

$$= -\nabla f_i \quad (\because H_i \text{ is Identity matrix})$$

(iii) Find the optimal step length $_1$ in the dim. S_i by one dimensional minimization technique (cubic interpolation method) and set,

$$X_{i+1} = X_i + \lambda_i^* S_i$$

(iv) Test the new point X_{i+1} for optimality. If all the variables have changed by the desired amount as specified earlier, terminate the iterative process. Else go to (v).

(v) Update the matrix H as,

$$H_{i+1} = H_i + M_i + N_i$$

where,

$$M_i = \lambda_i^* S_i S_i^T / S_i^T Q_i$$

$$N_i = -\frac{(H_i Q_i)(H_i Q_i)^T}{Q_i^T H_i Q_i}$$

and $$Q_i = \nabla f(X_{i+1}) - \nabla f(X_i)$$

$$= \nabla f_{i+1} - \nabla f_i$$

(vi) Set the new iteration number $i = i+1$ and go to (ii).

Eq. No.	Operation Name	Machining time (t_m) in min	Tool life (T) in min	Power (P) in kW	Force (F)/ Torque (T_d)
1	Turning	$\pi.D.L/(1000.V.f)$	$c(V^{c_1}.f^{a_2}.d^{a_3})$	$0.746.F_c.V/4500$	$F_c = d.f.\frac{\cos(\eta-\gamma)}{\cos([illegible]+\eta-\gamma)}$ [illegible] $[30.3\ C_2^{0.035}$ [illegible] $^{0.07}$ $-0.0105\ C_1 V$ [illegible] $]$
2	Drilling	$\pi.D_{dr}.(L+e)/(1000.V.f)$	$(\frac{T.[illegible] \times D_{dr}^{0.4}}{V.f^{0.7}})^{[illegible]}$ ++	[illegible] $.768$ [illegible] $f^{[illegible]}$ ++	–
3	Milling	$n.[illegible].D(L+e)/(1000.0.f.V.N_{ctr})$	$\frac{3.85\times10^4}{1.35}$ +	$0.746.$ [illegible] $.V/4500$	$T_d = 75.0$ [illegible] $.D_{ctr}$ $f^{0.72}[2(\frac{d}{D}-\frac{d^2}{D})^{1/2}]$
4	Milling Gear	$\frac{(a+ded).[illegible]_{tg}.\pi.D_{ctr}(L+e)}{d.1000.0\ [illegible]_{ctr}.V.f}$	$\frac{3.85\times10^4}{V^{1.35}}$		
5	Facing ⊗⊗	$R\|(f.N)$	$/V^{\varepsilon}$	$0.746.$ [illegible] $_c.V/4500$	

+ [13] ⊗ [9]
++ [12] ⊗⊗ [14]

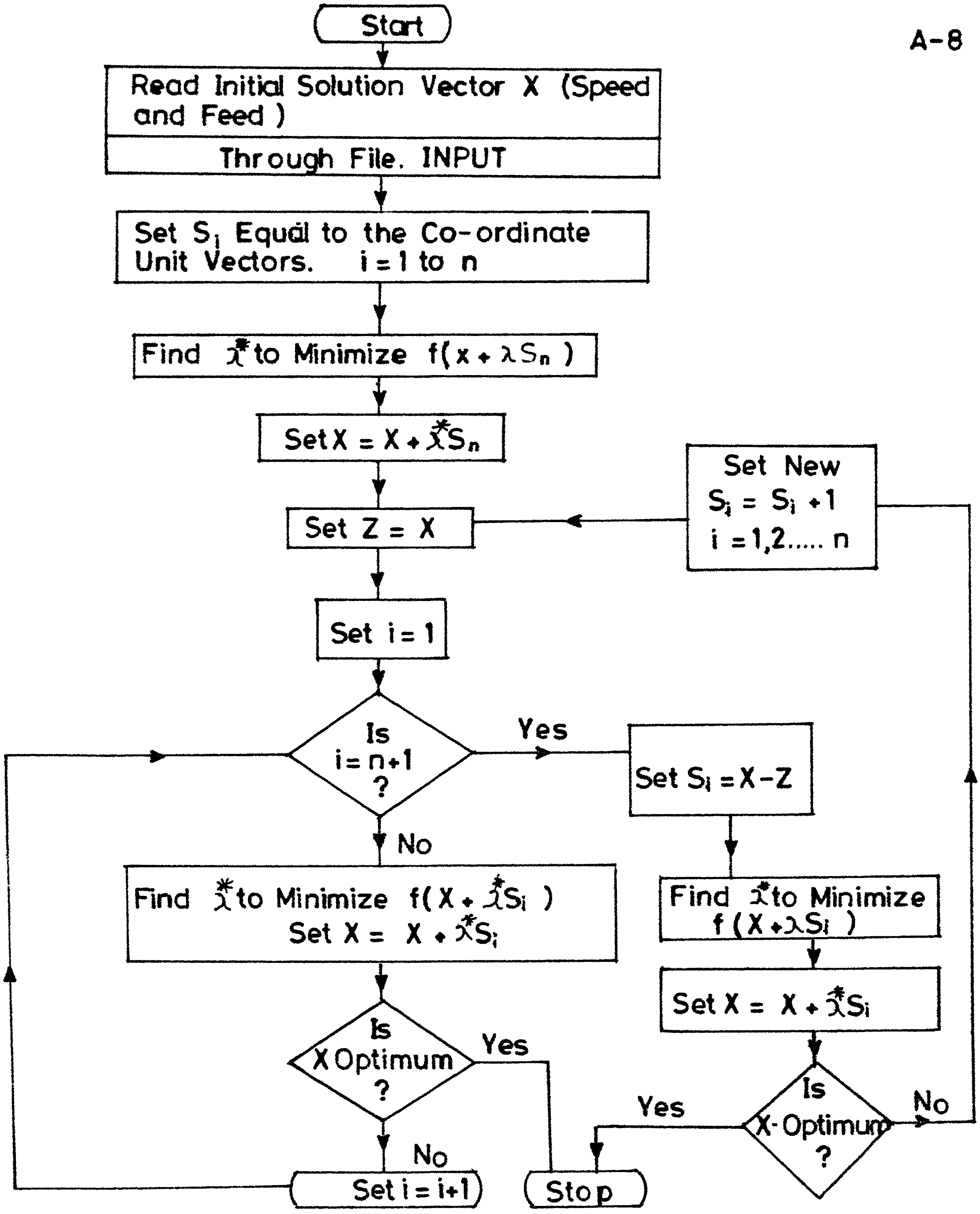

Fig. C.1 Flow Chart for Powel Method ([15])

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*   APPENDIX B_1   *
****

THE FALLOWING TABLE GIVES THE OPERATION DESCRIPTION AND THE CORRESPONDING CODE BEING EMPLOYED. THIS IS GIVEN TO INTERPRETE THE OPERATION_CODE USED IN THIS EXAMPLE.

	OPERATION DESCRIPTION	OPERATION CODE USED
1	DRILLING OF HOLE OF DIA. 30.0mm.	1201
2	ROUGH FACING OF THE END WITH 120.0mm IN DIA.	2301
3	FINISH FACING OF THE END WITH 120.0mm IN DIA.	2311
4	COUNTERBORING OF HOLE DIA 10.0mm TO 18.0mm.	103
5	DRILLING OF HOLE 10.0mm IN DIA.	120
6	ROUGH TURNING OF OUTER SURFACE LENGTH 120.0mm.	2201
7	FINISH TURNING OF OUTER SURFACE LENGTH 120.0mm.	2221
8	CHAMFERING AT THE END OF HOLE WITH DIA 30.0mm.	240
9	FINISH FACING AT END BB	2312

PROCESS PLAN OF THE PART IS AS FALLOWS

PART CODE : 1132222313
FAMILY CODE :
DATE : 6 MAR 87

MATERIAL : CAST IRON
BLANK SIZE: 130.0mm GREATER DIA. * 130.0mm LEN.
PART SIZE : 120.0mm GREATER DIA * 120.0mm LEN.

SLNO	OPCODE	MCTLCODE	DEPCUT (in mm)	OPTSPEED (in m/min)	OPTFEED (mm/rev)	MACH.TIME (in min)	SETUPTIME (in min)	NON-M/C TIME (in min)	PROCTIME (in min)	COST (in Rs)
1	1201	2	12.500	40.000	0.821	0.098	0.024	0.009	0.132	1.000
2	2201	5	0.350	115.312	1.249	0.129	0.032	0.012	0.175	0.362
3	2312	2	0.250	50.727	1.490	1.440	0.359	0.143	1.944	0.652
4	2301	2	0.500	15.818	1.499	1.152	0.288	0.115	1.555	2.920
5	2311	2	0.200	38.164	1.494	7.200	1.799	0.719	9.720	3.898
6	243	1	0.100	55.176	1.499	0.749	0.187	0.074	1.012	0.154
7	2221	5	0.100	161.035	1.237	0.094	0.023	0.009	0.127	0.637
8	120	3	5.000	53.552	1.749	0.004	0.001	0.000	0.005	1.023
9	103	1	0.500	38.418	0.998	0.749	0.187	0.074	1.012	0.154

NOTE : * INDICATES NON AVAILABILITY.

TOTAL PROCESSING TIME FOR THE PART (in MINUTES)= 15.685

TOTAL COST OF PROCESSING THE PART (IN Rs.)= 10.803

THE FOLLOWING TABLE GIVES A STATISTICAL INFORMATION REGARDING MACHINE TOOL OCCUPANCY, OCCUPANCY RATIO AND THE COST OF MACHIN-ING THE PART ON A PARTICULAR MACHINE.

TIME - INDICATES THE TOTAL TIME FOR WHICH THE M/C TOOL IS OCCUPIED BY THE PART.

RATIO - INDICATES THE RATIO OF THE TIME OCCUPIED BY THE PART ON ONE M/C TOOL AND THE TOTAL PROCESSING TIME.

M/C ING COST - IT IS THE TOTAL M/C ING COST OF THE PART ON TH-AT MACHINE.

M/C NO	TIME (IN min)	RATIO	M/C ING COST (IN Rs.)
1	2.02	0.12	0.309
2	13.35	0.85	8.470
3	0.00	0.00	1.023
4	0.00	0.00	0.000
5	0.33	0.01	0.999
6	0.20	0.04	0.000
7	0.00	0.00	0.000
8	0.00	0.00	0.000
9	0.00	0.00	0.000

****
* APPENDIX 3_2 *
****

THE FOLLOWING TABLE GIVES THE OPERATION DESCRIPTION AND THE CORRESPONDING CODE BEING EMPLOYED. THIS IS GIVEN TO INTERPRETE THE OPERATION_CODE USED IN THIS EXAMPLE.

	OPERATION DESCRIPTION	OPERATION CODE
1	BORING OF HOLE 26.0mm DIA.	101
2	DRILLING OF HOLE 20.0mm,LEN=135.0mm	1201
3	DRILLING OF HOLE 25.0mm,LEN=135.0mm	1202
4	SLOT MILLING:L=25.0,B=4.0,W=6.5	1501
5	SLOT MILLING:L=32.0,B=3.0,W=5.0	1502
6	GEAR MILL:OUTER DIA=51.94,WID=20.0	151
7	THREAD CUTTING:L=30.0,D=35.0	200
8	ROUGH TURN ON OUTER SURFACE,L=135.0	2201
9	FINISH TURN ON OUTER SURFACE,L=135.0	2221
10	ROUGH FACING OF END A DIA=35.0	2301
11	ROUGH FACING OF END B, DIA=51.94	2302
12	FINISH FACING OF END A,DIA=35.0	2311
13	FINISH FACING OF END B,DIA=51.94	2312
14	FINISH FACING OF STEP DIA=45.0	2313

NOTE: ALL DIMENSIONS IN mm.

L=LENGTH; B = DEPTH ; D=DIAMETER ; W = WIDTH .

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*  APPENDIX B_3   *
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THE FALLOWING TABLE GIVES THE OPERATION DESCRIPITON AND THE CORRESPONDING CODE BEING EMPLOYED. THIS IS GIVEN TO INTERPRETE THE OPERATION_CODE USED IN THIS EXAMPLE.

	OPERATION DESCRIPTION	OPERATION CODE
1	BORING OF HOLE 26.0mm DIA.	101
2	DRILLING OF HOLE 20.0mm,LEN=135.0mm	1201
3	DRILLING OF HOLE 25.0mm,LEN=135.0mm	1202
4	SLOT MILLING:L=25.0,B=4.0,W=6.5	1501
5	SLOT MILLING:L=32.0,B=3.0,W=5.0	1502
6	GEAR MILL:OUTER DIA=51.94,WID=20.0	151
7	THREAD CUTTING:L=30.0,D=35.0	200
8	ROUGH TURN ON OUTER SURFACE,L=135.0	2201
9	FINISH TURN ON OUTER SURFACE,L=135.0	2221
10	ROUGH FACING OF END A DIA=35.0	2301
11	ROUGH FACING OF END B. DIA=51.94	2302
12	FINISH FACING OF END A.DIA=35.0	2311
13	FINISH FACING OF END B.DIA=51.94	2312
14	FINISH FACING OF STEP DIA=45.0	2313

NOTE: ALL DIMENSIONS IN mm.

L = LENGTH ; B = DEPTH ; D = DIAMETER ; W = WIDTH .

PROCESS PLAN OF THE PART IS AS FALLOWS

PART CODE :	1272233013	MATERIAL :	CAST STEEL.
FAMILY CODE :		BLANK SIZE:	55.0mm GREATER DIA. * 190.0mm LEN.
DATE :	6 MAR 1987	PART SIZE :	55.0mm GREATER DIA. * 180.0mm LEN.

SLNO	OPCODE	MCTLCODE	DEPCUT (in mm)	OPTSPEED (in m/min)	OPTFEED (mm/rev)	MACH.TIME (in min)	SETUPTIME (in min)	NON-M/CGTIME (in min)	PRODTIME (in min)	COST (in Rs)
1	1201	4	6.000	55.314	1.499	0.040	0-010	0.004	0.055	0.209
2	1202	4	12.500	99.263	1.499	0.047	0-011	0.004	0.064	0.210
3	101	2	0.250	114.615	1.499	0.061	0-015	0.006	0.083	0.315
4	2301	2	0.500	39.999	1.498	0.106	0-026	0.010	0.144	0.253
5	2311	2	0.250	70.000	0.150	1.066	0-266	0.106	1.439	0.476
6	2302	2	0.500	44.999	1.496	0.201	0-050	0.020	0.272	0.302
7	2312	2	0.250	75.000	0.100	3.024	0-755	0.302	4.083	0.961
8	2201	5	0.250	114.784	1.499	0.058	0-014	0.005	0.078	0.258
9	2221	5	0.100	131.652	1.499	0.045	0-011	0.004	0.061	0.228
10	161	3	0.300	11.118	1.499	0.742	0-185	0.074	1.002	2.229
11	2313	2	0.100	59.999	0.326	0.006	0-001	0.000	0.009	0.201
12	200	2	0.150	11.118	1.499	0.749	0-187	0.074	1.012	0.15
13	1602	3	0.500	62.700	1.477	0.000	0-000	0.000	0.000	0.200
14	1601	2	0.700	78.174	1.456	0.004	0-001	0.000	0.006	0.200

NOTE : * INDICATES NON AVAILABILITY.

TOTAL PROCESSING TIME FOR THE PART (in MINUTES)= 8.245

-ING THE PART ON A PARTICULAR MACHINE.

TIME - INDICATES THE TOTAL TIME FOR WHICH THE M/C TOOL IS OCCUPIED BY THE PART.

RATIO - INDICATES THE RATIO OF THE TIME OCCUPIED BY THE PART ON ONE M/C TOOL AND THE TOTAL PROCESSING TIME.

M/C ING COST - IT IS THE TOTAL M/C ING COST OF THE PART ON TH-AT MACHINE.

M/C NO	TIME (IN min)	RATIO	M/C ING COST (IN Rs.)
1	0.00	0.00	0.000
2	7.05	0.84	13.210
3	1.00	0.12	2.429
4	0.11	0.01	0.420
5	0.14	0.01	0.487
6	0.00	0.00	0.000
7	0.00	0.00	0.000
8	0.00	0.00	0.000
9	0.00	0.00	0.000
10	0.00	0.00	0.000
11	0.00	0.00	0.000
12	0.00	0.00	0.000
13	0.00	0.00	0.000
14	0.00	0.00	0.000

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* APPENDIX 3_1   *
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THE FALLOWING TABLE GIVES THE OPERAITON DESCRIPITON AND THE CORRESPONDING CODE BEING EMPLOYED. THIS IS GIVEN TO INTERPRETE THE OPERATION_CODE USED IN THIS EXAMPLE.

	OPERATION DESCRIPTION	OPERATION CODE USED
1	DRILLING 10.5mm DIA.,LEN=40.C	120
2	ROUGH FACING OF END Y DIA.=24.0	2301
3	ROUGH FACING OF END X DIA.=20.0	2302
4	FINISH FACING OF END Y DIA.=24.0	2311
5	FINISH FACING OF END X DIA=20.0	2312
6	FINISH FACING OF TAPER END DIA=50.0	2313
7	COUNTERSINKING 13.0 DIA. TO 18.0 DIA.	250
8	SLOT MILL.L=30.0,W=5.0, D=4.0	160
9	BORING OF HOLE 10.5 DIA,L=40.0	101
10	KEYWAY MILL.L=60.0,W=5.0,D=2.0	152
11	ROUGH TURN FROM END Y TO TAPER.L=120.0 DIA.=35.0.	2201
12	ROUGH TURN FROM END Y TO TAPER.L=120.0 DIA.=30.0	2202
13	ROUGH TURN FROM END X TO TAPER EDGE. L=60.0,DIA=30.0	2203
14	FINISH TURN FROM END X TO TAPER EDGE. L=60.0, DIA=25.0	2221
15	FINISH TURN FROM END Y TO TAPER EDGE. L=90.0, DIA=24.0	2222
16	TAPER TURN.D1=50.0,D2=40.0,ALPA=7.8DEGREES.	223

PROCESS PLAN OF THE PART IS AS FALLOWS

PART CODE : 2632213003 MATERIAL : MILD STEEL.

FAMILY CODE :

BLANK SIZE: 55.00mm GREATER DIA. * 190.0mm LEN.

DATE : 6 MAR 87

PART SIZE : 50.0mm GREATER DIA. * 180.0mm LEN.

SLNO	OPCODE	MCTLCODE	DEPCUT (in mm)	OPTSPEED (in m/min)	OPTFEED (mm/rev)	MACH.TIME (in min)	SETUPTIME (in min)	NON_ M/CGTIME (in min)	PROCTIME (in min)	COST (in Rs)
1	2302	2	1.250	14.999	1.485	0.032	0.008	0.003	0.043	0.202
2	2312	2	0.250	59.996	1.485	0.200	0.049	0.019	0.269	0.202
3	2301	2	1.250	39.999	1.485	0.054	0.013	0.005	0.073	0.204
4	2311	2	0.250	55.559	1.494	0.337	0.084	0.033	0.456	0.204
5	2231	4	1.000	99.689	1.249	0.180	0.045	0.018	0.243	0.245
6	2232	5	1.000	99.425	1.249	0.084	0.021	0.008	0.114	0.221
7	2222	5	0.500	110.641	1.246	0.053	0.013	0.005	0.071	0.226
8	142	2	5.000	43.267	0.824	0.005	0.001	0.000	0.006	0.200
9	252	1	8.500	55.900	0.574	0.000	0.000	0.000	0.000	0.200
10	101	3	0.250	104.734	1.748	0.006	0.001	0.000	0.009	0.201
11	2233	1	1.000	99.346	1.249	0.056	0.014	0.005	0.075	0.270
12	223	5	0.500	110.641	1.246	0.749	0.187	0.074	1.012	0.154
13	2221	5	1.000	99.390	1.249	0.034	0.008	0.003	0.046	0.243
14	2313	1	0.250	59.656	0.990	0.150	0.047	0.014	0.202	0.201
15	152	2	0.900	39.473	0.825	0.002	0.000	0.000	0.003	0.200
16	152	2	0.500	64.999	0.825	0.006	0.001	0.000	0.009	0.200

NOTE : * INDICATES NON AVAILABILITY.

THE FOLLOWING TABLE GIVES A STATISTICAL INFORMATION REGARDING MACHINE TOOL OCCUPANCY, OCCUPANCY RATIO AND THE COST OF MACHIN-ING THE PART ON A PARTICULAR MACHINE.

TIME - INDICATES THE TOTAL TIME FOR WHICH THE M/C TOOL IS OCCUPIED BY THE PART.

RATIO - INDICATES THE RATIO OF THE TIME OCCUPIED BY THE PART ON ONE M/C TOOL AND THE TOTAL PROCESSING TIME.

M/C ING COST - IT IS THE TOTAL M/C ING COST OF THE PART ON TH-AT MACHINE.

M/C NO	TIME (IN min)	RATIO	M/C ING COST (IN Rs.)
1	0.20	0.07	0.401
2	0.86	0.32	1.415
3	0.00	0.00	0.201
4	0.31	0.12	0.516
5	1.24	0.47	0.846
6	0.00	0.00	0.000
7	0.00	0.00	0.000
8	0.00	0.00	0.000
9	0.00	0.00	0.000
10	0.00	0.00	0.000
11	0.00	0.00	0.000
12	0.00	0.00	0.000
13	0.00	0.00	0.000
14	0.00	0.00	0.000
15	0.00	0.00	0.000
16	0.00	0.00	0.000

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*   APPENDIX B_5   *
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THE FALLOWING TABLE GIVES THE OPERATION DESCRIPTION AND THE CORRESPONDING CODE BEING EMPLOYED. THIS IS GIVEN TO INTERPRETE THE OPERATION_CODE USED IN THIS EXAMPLE.

	OPERATION DESCRIPTION	OPERATION CODE USED
1	ROUGH FACE OF END A.DIA=45.0	2301
2	ROUGH FACE OF END B. DIA=35.0	2302
3	FINISH FACE OF END A. DIA=45.0	2311
4	FINISH FACE OF END B. DIA=35.0	2312
5	ROUGH TURN OUTER SURFACE.L=280.0	2201
6	FINISH TURN OUTER SURFACE.L=280.0	2221
7	TAPER TURN.D1=55.0,D2=40.0,ALPA=7.45 DEG.	223
8	COUNTERBORE.DIA=20.0,L=30.0	103
9	DRILL. DIA=15.0,L=30.0	120
10	COUNTERSINK.D1=25.0,D2=20.0,L1=5.0	240
11	INTERNAL THREADING.M15.0,L=20.0	190
12	END MILL(SLOT).L=30.0,W=5.0,D=4.0	161
13	SPLINE MILLING W=10.0,D=4.0	163
14	KEYWAY SHAPING.L=30.0,W=3.0,D=1.5	250
15	EXTERNAL THREADING.M35.0,PITCH=1.5	200
16	FINISH GRINDING OF SPLINES.	130
17	FINISH FACE OF SPLINE EDGE.	2313

NOTE ALL DIMENSIONS IN mm.

L = LENGTH ; D = DIAMETER ; B = DEPTH ; W = WIDTH.

THE FALLOWING TABLE GIVES A STATISTICAL INFORMATION REGARDING MACHINE TOOL OCCUPANCY, OCCUPANCY RATIO AND THE COST OF MACHIN-ING THE PART ON A PARTICULAR MACHINE.

TIME - INDICATES THE TOTAL TIME FOR WHICH THE M/C TOOL IS OCCUPIED BY THE PART.

RATIO - INDICATES THE RATIO OF THE TIME OCCUPIED BY THE PART ON ONE M/C TOOL AND THE TOTAL PROCESSING TIME.

M/C ING COST - IT IS THE TOTAL M/C ING COST OF THE PART ON TH-AT MACHINE.

M/C NO	TIME (IN min)	RATIO	M/C ING COST (IN Rs)
1	8.32	0.37	3.087
2	0.68	0.03	4.054
3	0.44	0.02	3.128
4	11.01	0.50	10.040
5	0.48	0.02	1.181
6	1.01	0.04	0.154
7	0.00	0.00	0.000
8	0.00	0.00	0.000
9	0.00	0.00	0.000
10	0.00	0.00	0.000
11	0.00	0.00	0.000
12	0.00	0.00	0.000
13	0.00	0.00	0.000
14	0.00	0.00	0.000
15	0.00	0.00	0.000
16	0.00	0.00	0.000
17	0.00	0.00	0.000

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*  APPENDIX B_5    *
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THE FALLOWING TABLE GIVES THE OPERATION DESCRIPTION AND THE CORRESPONDING CODE BEING EMPLOYED. THIS IS GIVEN TO INTERPRETE THE OPERATION_CODE USED IN THIS EXAMPLE.

	OPERATION DESCRIPTION	OPERATION CODE USED
1	ROUGH FACE OF END A.DIA=45.0	2301
2	ROUGH FACE OF END B. DIA=35.0	2302
3	FINISH FACE OF END A. DIA=45.0	2311
4	FINISH FACE OF END B. DIA=35.0	2312
5	ROUGH TURN OUTER SURFACE.L=280.0	2201
6	FINISH TURN OUTER SURFACE.L=280.0	2221
7	TAPER TURN.D1=55.0,D2=40.0,ALPA=7.45 DEG.	223
8	COUNTERBORE.DIA=20.0,L=30.0	103
9	DRILL. DIA=15.0,L=30.0	120
10	COUNTERSINK.D1=25.0,D2=20.0,L1=5.0	240
11	INTERNAL THREADING.M15.0,L=20.0	190
12	END MILL(SLOT).L=30.0,W=5.0,D=4.0	161
13	SPLINE MILLING W=10.0,D=4.0	153
14	KEYWAY SHAPING.L=30.0,W=3.0,D=1.5	250
15	EXTERNAL THREADING.M35.0,PITCH=1.5	200
16	FINISH GRINDING OF SPLINES.	130
17	FINISH FACE OF SPLINE EDGE.	2313

NOTE ALL DIMENSIONS IN mm.

L = LENGTH ; D = DIAMETER ; B = DEPTH ; W = WIDTH.

* APPENDIX P_6 *

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PROCESS PLAN OF THE PART IS AS FALLOWS

PART CODE	: 1532233033	MATERIAL	: MILDSTEEL.
FAMILY CODE	:	BLANK SIZE:	65.0mm GREATER DIA. * 255.0mm LEN.
DATE	: 6 MAR 1987	PART SIZE :	60.0mm * 245.0mm LEN.

SLNO	OPCODE	MCTLCODE	DEPCUT (in mm)	OPTSPEED (in m/min)	OPTFEED (mm/rev)	MACH.TIME (in min)	SETUPTIME (in min)	NON_ M/CSITME (in min)	PROCTIME (in min)	COST (in Rs)
1	2302	2	0.500	44.999	1.490	0.081	0.079	0.008	0.110	0.964
2	2312	2	0.250	60.000	0.150	0.816	0.204	0.081	1.102	2.441
3	2301	2	0.500	40.000	1.499	0.106	0.026	0.010	0.144	1.013
4	2311	2	0.250	65.000	0.100	1.599	0.399	0.159	2.159	4.003
5	2201	5	0.400	125.939	1.499	0.313	0.078	0.031	0.423	1.117
6	223	4	0.250	94.272	1.498	0.749	0.487	0.074	1.012	0.154
7	2271	4	0.100	70.000	0.100	7.408	1.852	0.740	10.001	9.885
8	2313	2	0.100	55.000	1.499	0.041	0.010	0.004	0.056	0.825
9	120	2	8.000	45.000	0.824	0.000	0.000	0.000	0.000	0.625
10	190	2	0.300	45.000	0.824	0.749	0.487	0.074	1.012	0.154
11	103	2	8.000	45.000	0.824	0.749	0.487	0.074	1.012	0.154
12	240	2	0.100	45.000	0.824	0.749	0.487	0.074	1.012	0.154
13	250	2	0.150	62.855	1.499	0.749	0.487	0.074	1.012	0.154
14	161	2	0.250	94.272	1.498	0.003	0.000	0.000	0.004	0.625
15	103	2	0.500	18.997	1.489	0.357	0.089	0.035	0.483	3.156
16	200	2	0.250	62.855	1.499	0.749	0.487	0.074	1.012	0.154
17	130	6	0.250	94.272	1.498	0.749	0.487	0.074	1.012	0.154

THE FALLOWING TABLE GIVES A STATISTICAL INFORMATION REGARDING MACHINE TOOL OCCUPANCY, OCCUPANCY RAITO AND THE COST OF MACHIN-ING THE PART ON A PARTICULAR MACHINE.

TIME - INDICATES THE TOTAL TIME FOR WHICH THE M/C TOOL IS OCCUPIED BY THE PART.

RATIO - INDICATES THE RATIO OF THE TIME OCCUPIED BY THE PART ON ONE M/C TOOL AND THE TOTAL PROCESSING TIME.

M/C ING COST - IT IS THE TOTAL M/C ING COST OF THE PART ON TH-AT MACHINE.

M/C NO	TIME (IN min)	RATIO	M/C ING COST (IN Rs)
1	0.00	0.00	0.000
2	9.12	0.42	14.431
3	0.00	0.00	0.000
4	11.31	0.51	10.040
5	0.42	0.01	1.117
6	1.31	0.04	0.154
7	0.00	0.00	0.000
8	0.00	0.00	0.000
9	0.00	0.00	0.000
10	0.00	0.00	0.000
11	0.00	0.00	0.000
12	0.00	0.00	0.000
13	0.00	0.00	0.000
14	0.00	0.00	0.000
15	0.00	0.00	0.000
16	0.00	0.00	0.000
17	0.00	0.00	0.000